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BACTERIOLOGICAL WATER QUALITY STUDY EXAMINING THE IMPACT OF SEDIMENT AND SURVIVAL TIMES IN THE HUMBER RIVER AND BLACK CREEK

R.A.C. PROJECT NO. 198G

Prepared for Environment Ontario by:

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RECYCLABLE

ACKNOWLEDGEMENT AND DISCLAIMER

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DISCLAIMER

PUBLICATIONS RELATED TO THIS PROJECT

Seyfried, P.L. and E. Harris. Humber River/Black Creek: detailed bacteriological water quality study examining the impact of sediment and survival times. Proceedings Technology Transfer Conference Part B, Water Quality, The Sheraton Centre, Toronto, December 8-9, 1986. Sponsored by the Research Advisory Committee, Ministry of the Environment, pp. 347-391.

ABSTRACT

Bacterial transfer between the water column and bed sediments was studied to determine the potential for sediment resuspension to contribute to bacterial loading in areas impacted upon by different point and non-point pollution inputs. The possible impact of stream flow on sediment resuspension was also examined. The sediment bacterial contributions were measured during dry weather (before and after mechanical agitation of the sediment bed), wet weather conditions, and intermediate periods sampled within 2 days after a rainfall event. The six locations chosen for sampling were situated along both the upper and lower Humber River and Black Creek, and represented various pollution input types. The sampling sources included:

1) a priority storm sewer outfall,
2) a combined sewer outfall,
3) near the mouth of a creek receiving industrial waste,
4) an area impacted upon by waterfowl,
5) a cattle access area, and
6) a sanitary sewer outfall.

During dry weather conditions, at locations where point source bacterial loadings were consistently high i.e. a dry weather storm sewer flow with high fecal indicator levels or at locations directly impacted upon by animals, water column samples taken after mechanical sediment agitation exhibited higher levels of fecal coliforms and <u>E. coli</u> than did the pre-agitation

samples. Sediment agitation in areas impacted upon by intermittent or weather dependent pollution inputs, i.e. combined sewer outflows, did not contribute to a significant increase in E. coli contamination in the water column.

During wet weather, under increased flow conditions, detection of instream point sources was obscured by upstream contamination from other sources and from resuspended sediment. The densities observed were usually higher than those induced through dry weather sediment agitation suggesting that sediment resuspension is only one of the contributing sources of bacterial pollution during storm events.

The instream survival times of various fecal indicator bacteria were measured at each location and appeared to be influenced by such site-specific factors as temperature, flow, nutrient and/or chemical pollutants, water depth and clarity. Overall, E. coli and S. faecalis exhibited rapid die-off in warmer waters ($\geq$ 20^{o}c) while S. faecium survived for longer periods. In late fall (water temperature < 10^{o}c), all three indicators showed extended survival patterns. S. bovis exhibited very rapid die-off (i.e. greater than 90% reduction in 24 hrs.) in cooler waters (< 10^{o}c).

CONCLUSIONS

Bacterial exchange between the bed sediments and water column does occur when sediments are suspended; however, the extent to which this process occurs depends on:

1. the survey location (i.e. type of pollution input, hydrology and geomorphology of the area);
2. the sampling site at a given location (i.e. relative to the input);
3. the flow rate of the river and prevailing weather conditions; and
4. the bacterial parameter being analyzed.

The effect of sediment resuspension is greatest near the source of the input, but impacts occur downstream as well.

The results of this study indicate that pollution inputs having a direct impact on the water column do not necessarily cause the greatest loadings to the system. Detection of major dry weather pollution inputs can be aided by sampling after mechanical sediment agitation during extended periods of dry weather as bed sediments may better reflect the magnitude of the input.

The greatest accumulation of contaminants to the sediments occur at locations where sediment deposition is combined with continuous high level pollution inputs. The greatest local impact appears to be in areas receiving direct fecal deposits. However, the overall degradation of water quality in the Humber

River watershed appears to be due to the cumulative effect of a large number of different sources. Localized effects are not indicative of the impact of any one pollution type on the entire water course.

Significant correlations between flow, suspended sediment and fecal indicator bacteria were not always found signifying the complexity of the system due to the variety of the pollution inputs, sediment types and sediment-bacterial relationships. The sampling program was also not designed to elucidate this type of information and was thus insufficient in intensity. However, the instream data did show that suspended sediment in the water column increased with increased flow and a major contribution to suspended sediments during wet weather will result from resuspension and transport of bed sediments. If one compares the bacterial levels achieved after Mechanical Sediment Resuspension (MSR) to wet weather concentrations, it becomes obvious that resuspension of contained sediments will have a significant impact on bacterial water quality during wet weather. This will be particularly evident in areas where there are continuous dry weather contaminant inputs as these inputs appear to off-set the die-off of fecal indicator bacteria in the river.

Because the accumulation of Fecal Indicator Bacteria (FIB) in the sediments are essentially a magnification of ongoing or continuous dry weather inputs and are not part of the normal sediment bacterial flora, a significant reduction in dry weather pollution inputs could not only improve water quality during dry

weather but could also cause a significant decrease in sediment bacterial deposits. (An intensive loading study of restricted sites with known inputs might provide more information on the potential magnitude of any change). This in turn would result in a decrease in loadings during wet weather. The net effect in a system such as the Humber River would be a decreased impact on the lake under both dry and wet conditions. Wet weather inputs (i.e. surface run-off containing animal feces, storm and combined sewer overflows) will continue to affect sediment loadings unless they are totally flushed out of the system during a storm. This will off-set the improvements attained through dry weather input control. Therefore, any improvement made to reduce wet weather loadings will benefit the system under both wet and dry weather as well.

In determining the source of the pollution input (i.e. human or non-human), it is necessary to develop an interpretive methodology combining information obtained from different types of data (e.g. site observation, upstream and effluent inputs, bacterial concentrations and relationships). Reliance on one piece of information such as the FC/FS ratio, is not sufficient. Characterization of group D streptococci from surface waters can aid in identifying pollution sources, however, this type of analysis would be better suited to restricted sampling situations such as inpipe sampling. Interpretive tools such as EC/FC ratios may be of use in determining the age of a pollution input.

Bacterial survival in rivers and other watersheds depends on site specific factors such as nutrient and chemical pollutant loadings, water temperature (i.e. seasonal variation), and upon the bacterial species itself. There is a general trend towards initial rapid die-off followed by a levelling off of the die-off rate due to the environmental adaptability of survivors. This would result in the prolonged survival of more hardy bacterial strains in surface waters and bed sediments. Bacterial survival under cold temperature conditions would lead to a greater impact of bacterial contamination during spring run-off periods.

RECOMMENDATIONS

1. This study demonstrated that sediment accumulations of bacterial contaminants can act as a sensitive indicator of the historical and ongoing pollution impacting on a given site. It is therefore recommended that an analysis of sediment quality by direct examination or more preferably after resuspension into the water column, be included in water quality surveys.

2. In order to better understand the impact that resuspension and transport of sediments may have on a specific body of water, an analysis should be made to determine the relative abundance of different size fractions in the sediment and the fraction(s) with which indicator bacteria preferentially adsorb within the watershed under study.

3. Since the impact of a given source input is quickly masked upon entering a large body of water, especially if the impacted body is already polluted, it is necessary to use intensive sampling above and below any input being studied. The use of transects across a river or a zonal grid approach in lakes is better than the use of single stations.

4. It was apparent from this project that not all FIB reacted with equal sensitivity to different pollution impacts. Thus, it is recommended that water quality surveys conducted

for the purpose of locating or determining the impact of pollution inputs utilize a number of bacterial parameters.

5. Further work should be conducted to establish the factors affecting different responses in the FIB to improve their interpretive significance; i.e. the meaning of changes in EC/FC vs. FC/FS or FS vs. ENT as well as the PSA response. A great deal of the information required may come from their use in properly designed surveys.

6. When it is necessary to establish relationships between different environmental factors such as rainfall, flow, suspended sediment and pollution indicators such as bacteria, surveys which are both intensive spatially as well as temporally are required.

7. The study data provided further evidence that the FC/FS ratios of 4.0 and 0.7 can not be used to distinguish human and non-human inputs. It is therefore recommended that changes in the FC/FS ratios be used as an indicator of fecal input and change in relative quality of the input but that attempts to use it to establish an original source be approached with caution. Interpretations should be based upon information from recent fecal studies (P. Seyfried, E. Harris and M. Young, 1986 unpublished).

8. The speciation of fecal streptococci populations can help elucidate the source of fecal pollution; i.e. human vs. non-human and should be included in water quality surveys for this purpose. This approach is most useful when being used in conjunction with point source inputs; e.g. high priority storm sewers. The value of using less specific; e.g. KF agar vs. more specific; e.g. m-ME agar should be investigated.

9. This study demonstrated differences in bacterial populations in different sources investigated. A method for detecting the presence of sanitary waste is storm sewers could be developed by characterizing and comparing the bacterial populations in storm water, sanitary sewage and "high priority" storm sewers servicing the same areas.

10. Since bacterial survival changes from location to location it is necessary to assess the specific die-off rates for any location for which a bacterial water quality model is being developed. Studies should be conducted in the sediment as well as the water column.

11. Additional studies should be conducted to determine the relationships that exist between bacterial survival and the presence of various nutrients and toxic chemicals. This should also be examined as a potential bio-monitoring tool for the detection of toxic chemicals.

12. To better assess the transport of bacteria in a dynamic aquatic ecosystem, non-pathogenic bacterial tracers should be developed and tested; e.g. nalidixic acid resistant E. coli.

13. The project results support recommendations made in the other reports; e.g. Humber River Management Plan, on the need to reduce dry and wet weather fecal pollution loadings to the Humber River from sources such as CSO'S, Emery Creek, Black Creek and animal fecal matter. Reduction of pollution loadings to the Humber River will not only have a direct effect on the water column, but will reduce accumulations in the bed sediment. It is further recommended that monitoring for improvements as a result of remedial actions include sediment quality.

14. Since other bacterial survival studies looking at die-off in sediment environments indicate extended survival (G. Palmateer, personal communication, Lake Simcoe Region Conservation Authority RAC study, ongoing) removal of contaminated sediments from recreations areas may have to be considered if a rapid recovery is desired after pollution inputs have been removed.

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2/01/98

Happy New Year Garry!

Sorry for the delay in getting these paper to you. They are from the proceedings of the WQTC conference held in Denver, November.

There is one other paper that I am trying to locate by Gordon McFeters, which I will fax once I find it.

Regards,

Shelley [signature]

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ABBREVIATIONS

MSR	-	mechanical sediment resuspension
SED	-	sediment
S.SED	-	suspended sediment
FIB	-	fecal indicator bacteria
FC	-	fecal coliforms
EC	-	*Escherichia coli*
PSA	-	*Pseudomonas aeruginosa*
ENT	-	enterococci
FS	-	fecal streptococci
UP	-	upstream site
DN1	-	first downstream site
DN2	-	second downstream site
SSO	-	storm sewer outfall
CSO	-	combined sewer outfall

INTRODUCTION

Understanding the impact of fecal pollution inputs to a surface water body requires a knowledge of the input type and an understanding of the instream processes which determine the effect that a given input may have on downstream water quality. Two such processes which may contribute to downstream contamination from point and non-point pollution sources are: a) bacterial transfer between the water column and bed sediments under agitated sediment conditions; and b) bacterial survival.

Bacteria are more commonly found associated with solid particles rather than free-floating in the aquatic environment. Sayler, et al (1) found that up to 53% of viable bacteria in surface waters associate with particulate matter. The mechanism of bacterial attachment to solid surfaces is by adsorption (2, 3). Bacteria are attracted to the water-solid interphase by various forces of attraction. Long range forces i.e. Van der Waals, gravitational, hydrodynamic and diffusional forces are required to move the bacteria close enough to the solid surface so that short range specific forces of attraction i.e. chemical bonding, charge attraction, ion pair formation can take place (4). It is through these ongoing attraction processes that both free floating bacteria and bacteria-particle aggregates are continually removed from the water column to form part of the bed sediments.

Previous studies of the bacterial populations in sediments have reported that sediment bacterial concentrations are considerably higher than that of the overlying water column (5-9,

19, 24). Levels of heterotrophic bacteria between 1.17×10^8 to 9.97×10^9 per gram dry sediment have been reported (10). The bulk of bacteria in sediments reside in the surface layers where their activity is important to the mineralization of organic matter (11-12). Many of the species present in bed sediments are normal inhabitants and can adapt to the changing conditions of this environment.

Fecal coliform and enteric pathogenic bacteria have also been recovered from the upper 5 cm of the sediment bed. Hendricks (5) found that a higher rate of recovery of Salmonella sp. could be obtained from sediments than from water. Geldreich (13) isolated Salmonella organisms from 23.5% of mud samples taken when fecal coliform levels in the overlying water column were less than 200/100 mL. Other workers (6) have shown that higher recoveries of fecal coliform bacteria (100 to 1,000 fold increases over water column levels) may be obtained from sediments and have suggested that sediments may serve as a more concentrated and stable index of water quality. Although some species within the fecal coliform group may occur naturally in sediments due to such processes as soil erosion, i.e. Citrobacter spp. and Enterobacter spp., the presence of E. coli in the sediment environment is transient and due solely to fecal pollution input to the aquatic system.

The degree to which E. coli and other fecally excreted coliform bacteria can be recovered from sediments depends upon several factors, the most obvious of these being the frequency

and degree of fecal contamination from pollution inputs (14). High fecal coliform levels have been detected in sediments extending several miles from outfalls discharging primary sewage effluent (15). A consistent input from point and non-point fecal pollution sources will lead to high bed sediment levels of these bacteria as sedimentation processes occur.

Survival of fecal indicator bacteria in sediments is an important criteria in determining the extent to which they may be found in this environment. Extended survival and even multiplication of fecal coliforms in sediments have been shown to occur (7,8). Such observed phenomenon may be due to certain attributes of bed sediments that are conducive to the establishment of favourable microhabitats. Levels of organic nutrients and growth factors such as phosphorous and nitrogen are high in sediments (16,17). About 50% of the photosynthesized organic carbon and most of the allochthonous carbon settles in the sediment (9, 18). The organic carbon levels in sediment may reach as high as 10g/L while levels in the water column fall usually in the range of 10^{-3} to 10^{-2}g/L. Similar ratios hold for ammonium, organic nitrogen and phosphorous (19). The nutrient content of sediments will depend upon the pollution input type impacting upon a given area.

Characteristics possessed by the fecal indicator bacteria such as their ability to metabolize benthic nutrients (7,8), withstand predatory pressure (8,20,21), and metabolically compete with other microbes (8,21) will dictate the length of time of

their survival in the sediments. Such characteristics will depend upon the bacterial species being introduced into the sediment environment.

The sedimentation rates of bacterial/particulate aggregates will vary in different surface water bodies because they are affected by many variables such as the adsorption capacity of both the sediment and the bacteria. Adsorbance is dictated most specifically by the surface chemistry of the microbe (22). The concentration of bacteria present at the water-solid interphase can effect the degree of adsorption leading to possible saturation of the sediment surface (23,24,32). Different sediment types will display differing degrees of adsorption. Inorganic particles in sediments are classified according to size into coarse sands (200-2000 µm diameter), fine sands (20-200 µm D.), silts (2-20 µm D.) and clays (<2 µm D.) (4). Generally, smaller particles, i.e. clays and those having greater surface areas than smooth spheres, are better adsorbents (4). The adsorption capacity of sediments is largely determined by the amount of clay mineral they contain and thus also related to sediment texture and surface area (25). Coarse sandy sediments have a particle surface area of approximately $20cm^2/g^{-1}$ and tend to make poor adsorbent material (4,29). Clays can have a surface area in excess of $20,000cm^2/g^{-1}$ and thus make the best adsorbents. Clays also have an added benefit for adsorbed bacteria in that they provide protection from radiation and predator-prey interactions (4).

Some environmental factors affect the rate of sedimentation because they affect the adsorbance ability of the bacteria to sediment particles. A pH >6 will interfere with adsorbance, while the presence of electrolytes and increased salinity will enhance floculation and sedimentation of bacteria and suspended particles. Subsequently, decreasing the salinity will cause desorption of the bacteria from sediments (26).

The depth of the water column above the bed sediments will influence the rate of sedimentation solids and the bacteria adsorbed to them with shallow systems displaying an increased sedimentation rate. The sediments of shallow lakes have been found to harbour high levels of fecal indicator bacteria (27) and it has been proposed that sedimentation may be a major mechanism for removal of bacteria from these water bodies (27).

Sediment resuspension in shallow lakes and other surface waters may occur quite easily due to increased discharge rates, waves, and other wind induced turbulence, motor boats, swimming, and wading (27). Severe water quality impairment from sediment resuspension in lakes, estuarine waters and rivers has been previously documented. A study of Vembanad lake in Cochin, India revealed that bed sediments were acting as reservoirs of fecal indicator and pathogenic bacteria. Heavy boat traffic, dredging, tides and waves contributed to the continual resuspension of sediments in the lake causing water quality deterioration (17). Studies conducted in the Lynhaven Estuary (28) also showed sediments to be reservoirs of enteric bacteria in densities

sufficiently to cause water quality deterioration and pose potential health hazards. McSwain (29) found that elevated stream levels of total and fecal coliform bacteria during storms were more related to bottom sediment disturbances than to surface run off. Krunkle (30) also made this conclusion after studying the influence of various land use practices on bacterial water quality.

Rivers and other watersheds represent a more dynamic system for studying the effects of sediment resuspension than lentic waters. Watersheds may be viewed as multiple storage and release systems (31) where water and sediment bacterial populations are in a constant state of interchange; i.e. bacterial content in the water column is increased by fecal pollution input and sediment resuspension and is reduced by sedimentation and die-off. In a study of rivers by Matson et al. (27) the authors reported that during stable flow conditions, sediment and water bacterial populations achieved equilibrium with a noted shift towards sediment bacterial levels. When river discharge increased; i.e. storm events, sediment organisms were scoured from the sediment surface into the water column and along with surface run-off lead to increased water densities. This event was found to reach a maximum at or just before peak river discharge. At peak discharge, the bacterial levels in the water column began to decrease due to dilution and because sediment resuspension and surface run-off had ceased. Levels in both the water column and

sediment returned to their former equilibrium after a system-specific time period.

Jenkins et al. (31) proposed a process based model of fecal bacterial dynamics in which the stores and mechanisms of movement of bacteria through a catchment could be represented by a simple mass balance model acting through a series of stores. The land surface store receives fecal input from animal excrement and agricultural practices. Transport of bacteria from land surfaces to the river sediments proceeds through overland flow, through-flow and pipeflow. In-stream movement is brought about by stream stage rises and increases in velocity causing turbulence and bottom erosion. The bacteria are held in flow until they undergo sedimentation due to velocity decrease at some point downstream.

Thus, according to these previous studies, sediment resuspension and deposition are stream flow dependent processes whereby increased flow facilitates the former and decreased flow, the latter. How far bacteria are transported during high flow conditions depends on stream flow velocity. In the aforementioned study by Matson et al. (27), regression equations of the percent decrease in fecal indicator densities in water between two stations located 2.7 Km. apart showed that minimal decrease occurred at high stream velocity (discharge). Since no additional inputs occurred along this portion of the river, the authors concluded that bacteria from upstream inputs were being transported downstream and that no sedimentation was occurring because of the high flow.

Particle size association between bacteria and suspended solids can influence the extent to which bacterial contamination will be deposited downstream. As previously mentioned bacteria generally adsorb better to smaller particles and association with a specific size fraction has been documented. Wood (32) found that optimum adsorption occurs on particles ranging from 1 to 2 µm in diameter and adsorption to a lesser extent occurs on particles ranging from 5 to 20 µm. In most cases resuspension of these smaller particles will occur more readily under increased flow conditions and it is possible that the high base flows of some rivers or streams might affect resuspension and transportation of smaller particles during dry weather conditions. River discharge during storm events would certainly achieve resuspension of these and even larger sized particles and would facilitate transportation of particulate matter over considerable distances before a return to normal flow could allow sedimentation to occur. Under these conditions, survival in the water column will determine how far the bacteria may be transported.

Generally water represents a more harsh environment for bacteria than sediments. The levels of available nutrients will be lower than those found in sediments and will vary depending upon the type of pollution input. Where nutrient levels are low, die-off may proceed more rapidly. Water with high dissolved organic carbon content, i.e. those impacted upon by sewage effluent, may allow for extended survival or even support

regrowth of heterotrophic bacteria (33). The presence of toxic materials in surface waters will have a detrimental effect on the survival of some types of bacteria (34, 35). Changes in water pH will affect the survivability of bacteria (36) as will depth of sunlight penetration (37). Temperature is also known to have an effect on bacterial survival. Water temperature may be less stable than bed sediment temperature and may be affected by fluctuations in air temperatures. Generally higher water temperatures result in increased bacterial metabolism and thus an increased rate of die-off when insufficient nutrients are present, while low temperatures tend to retard metabolism and permit extended survival by allowing the bacteria to exist in a dormant state. Mitchell and Starzyk (39) found that both Escherichia coli and Salmonella typimurium exhibited a 90% survival rate for up to 16 days when surface water temperatures were 5^{o}C; but that the 90% survival rate decreased to less than 10 days once water temperatures reached 10^{o}C or above. McFeters et al. (41) found that E. coli survival response to temperature was inversely proportional between 5-15^{o}C, but that above 15^{o}C temperature became a less important factor in survival. Thermal stress can be beneficial to certain bacterial species depending upon their ambient growth temperatures. Regrowth of Pseudomonas aeruginosa in polluted waters at high temperatures can occur (41) especially when coupled with a high water organic content. Some fecal coliform bacteria, e.g. Klebsiella sp., will also exhibit regrowth under these conditions (41).

Survival in surface waters will thus depend upon the bacterial species present and its response to various environmental factors. Even under favourable conditions, i.e. high nutrient content, some fecal indicators, e.g. E.coli, will die-off more rapidly than others, e.g. S. faecium (42) possibly because of their different cell wall structure. Even members of the same genus, e.g. Streptococcus, will exhibit differential die-off in surface waters. For example, it has been documented that S. bovis has a very short survival time of 24 hours in surface water regardless of water temperature or organic content (43), whereas, S. faecalis and S. faecium survive for much longer periods (i.e. > 42 days) (42). S. faecalis will not however survive as well as S. faecium in warmer polluted waters (Dufour personal communication, 1985).

The purpose of this study was to observe the potential for bacterial transfer between the water column and sediment beds in the Humber River and Black Creek watersheds and to determine the survival times of various fecal indicator bacteria in both these aquatic environments. The effect of different pollution inputs will be compared with respect to their relative impact on water and sediment quality. The information provided by this work will assist in answering some of the questions related to actual transport mechanisms and bacterial responses in the Humber River and Black Creek and their bacterial loading contributions to the lakefront. This study also provides information on pollution source determination in the Humber River and Black Creek

watersheds by characterization of the fecal streptococci populations recovered from both bed sediment and water column samples collected near the different pollution inputs.

METHODS

Sampling Location: Selection and Description

Six sampling locations were chosen at various points in the upper and lower Humber River and Black Creek. The sites were selected to provide study areas affected by different types of pollution sources.

The study sites included:

#1. Lower Humber River near Elhart Drive (priority storm sewer #250[1]);

#2. Black Creek near Hyde Avenue (combined sewer #159);

#3. Lower Humber River at Emery Creek (receives industrial effluent);

#4. Lower Humber River at James Gardens (gull and geese roosting islands);

#5. Upper East Humber River at Teston Road (cattle access area);

#6. Upper Humber River at Bolton (Bolton Sewage Treatment Plant).

A geographical map of the location is presented in Fig. 1.

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[1]TAWMS Technical Report #1, Humber River Dry Weather Outfall Survey.

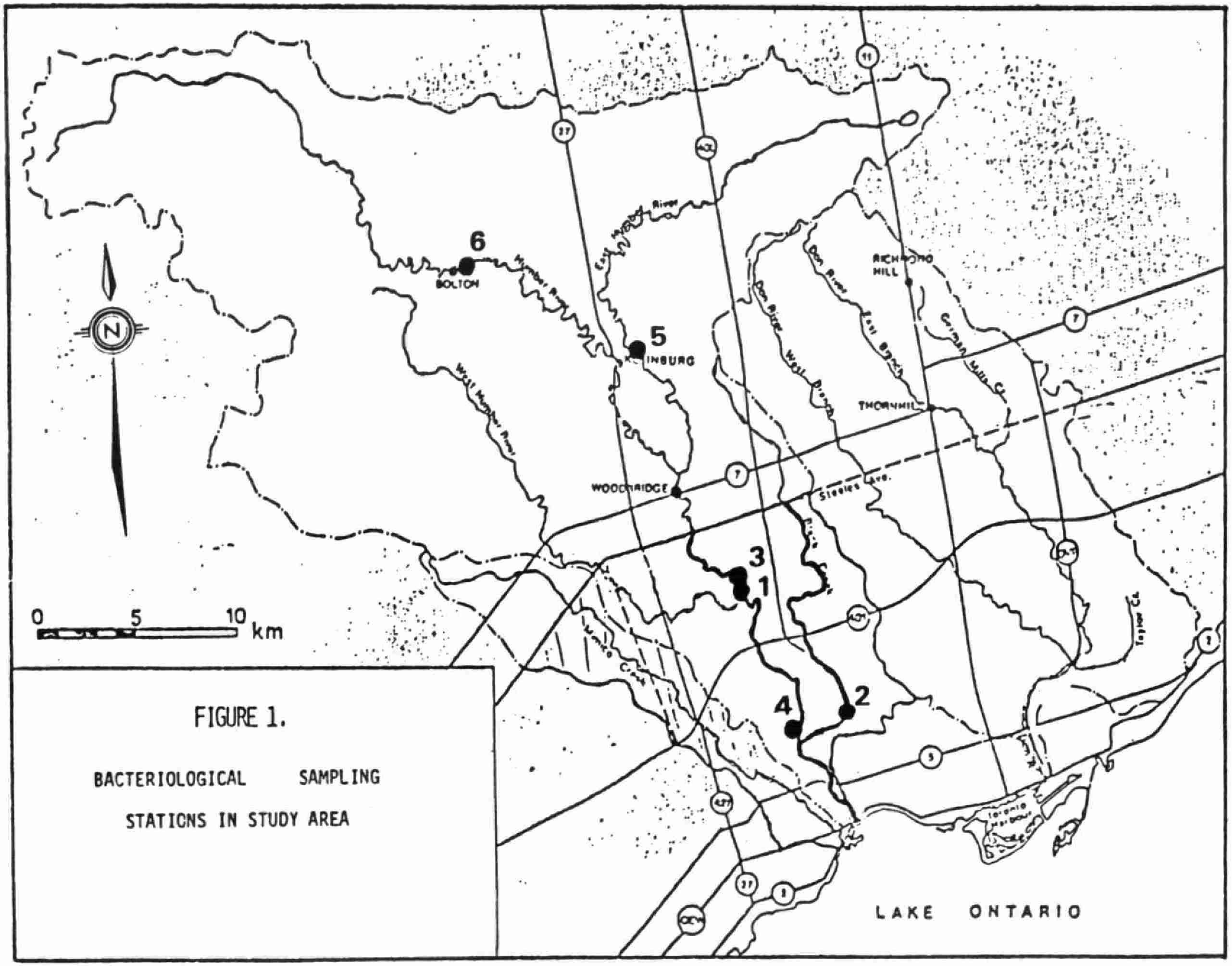

FIGURE 1.

BACTERIOLOGICAL SAMPLING STATIONS IN STUDY AREA

A total of four in-stream sampling points were chosen at each location in order to delineate the input source. These sites included:

1. 25-30 meters upstream of the source;
2. at source (immediately downstream of the pollution input);
3. 25-30 meters downstream; and
4. 50-60 meters downstream. Outfall samples from the sewer as well as samples from Emery Creek were also taken.

Sampling for both dry and wet weather surveys was conducted during the months of June, July and August, 1986.

__Sampling Procedures: For Sediment Resuspension Analysis__

__Dry Weather__

Dry weather samples were collected from each of the six locations by alternating 3 locations per week. The locations were divided according to the upper and lower Humber River boundary (i.e. below or above Steeles Avenue). The Humber River at Emery Creek was sampled with the two upper Humber River locations; dry weather sampling was conducted over a 3 day period that was preceded by a minimum of 2 dry weather days.

Beginning at the farthest downstream site, a sample of mid-depth water column was collected. Then, using a rake, the river bottom was agitated until sediment resuspension was visible at which time a second mid-water column sample was taken. This same procedure was performed at each site, moving in an upstream

direction. The samples were labeled according to the site and whether they were taken before or after sediment agitation.

Outfall samples from the sanitary and storm sewers were taken directly from the pipes. (Outfall samples from the combined sewer could only be taken during wet weather events since the sewer did not exhibit flow in dry weather.) Water column samples from Emery Creek were taken at a distance of a metre above its confluence with the Humber River. Post sediment agitation samples could not be obtained from within the Creek because of gabion obstruction. All samples were transported on ice to the laboratory where they were analyzed within 24 hours.

Wet Weather

Wet weather sampling was conducted at each of the sites at the commencement of a precipitation event or within 24 hours after a rainfall and continued over a 3 day period. Post-rainfall periods (i.e. 24 to 48 hours after a rainfall) were considered to be intermediate weather conditions. During storm events, only nonagitated water column samples were taken as it was not possible to increase the naturally occurring sediment resuspension by mechanical agitation. Wet weather samples were also transported on ice to the laboratory and analyzed within 24 hours after sampling.

Sampling Procedure: Survival Studies

In situ survival studies of fecal indicator bacteria were conducted at all six locations during the summer and again in late October and mid-November in order to obtain survival rates under warm and cold weather conditions. The studies were performed using dialysis membrane filter chambers with volume capacity of approximately 50 mls (40) (see Appendix A-1 for description and use of chambers). At some of the sites, 100 ml capacity chambers were also used to compare the effect of a greater surface area to volume ratio. The chambers allow for transference of molecules (e.g. gases, organic nutrients) between the water column and a pure culture of bacteria without contaminating the culture by introducing new water-borne bacteria into it. Pure cultures of *Escherichia coli*, *Klebsiella pneumoniae*, *S. faecalis*, *S. faecium* and *S. bovis* were inoculated into sterilized chambers to complete volume capacity (see Appendix A-2 for pure culture preparation). The inoculated chambers were transported to locations in containers of Humber River water kept on ice in a cooler. At each location the chambers were placed in baskets which were then submerged and anchored at the source sampling site. Chambers were placed in the river on Monday morning and sampled for three consecutive days by aseptically removing a small volume of culture and transporting it back to the lab on ice. River temperatures were recorded each day of the survival study period to determine the effect of temperature on survival.

<u>Sample Analysis</u>

Analysis of the samples for fecal indicator bacteria and *P. aeruginosa* was by membrane filtration of appropriate dilutions of the samples through Gelman GN6 47 mm cellulose nitrate filters with a pore size of 0.45 µm (46). The filters were planted on media appropriate for the recovery of the various indicator bacteria.

Fecal coliform bacterial densities were determined by planting the filters on m-TEC agar (44) and incubating for 23 $\pm$ 1 hours at 44.5 $\pm$ 0.5^{o}C. Both target and non-target colonies were counted. Target colonies were yellow, yellow-green and yellow-brown; non-target colonies were blue to blue-green in colour. To ensure the accuracy of the counts, only results obtained from filters with target counts of between 10 and 100 colonies were used to calculate the bacterial density per 100 mL of water sample.

A second step for the determination of *E. coli* by urease treatment (45) was incorporated into the m-TEC procedure. Filters with appropriate target counts (i.e. between 10 and 100 target colonies) were removed from the m-TEC plates and placed on filter pads soaked in a urea/phenol red solution. The filters remained in contact with the filter pad for 15 mins. to allow for deaminization by non-*E. coli* coliform bacteria processing urease. A second count of all urease negative colonies (all yellow, yellow-green and yellow-brown colonies) was taken.

Fecal streptococci determinations were made by planting the filters on m-Enterococcus agar (Difco) (46). The medium was incubated for 48 ± 2 hrs. at 35 ± 0.5^{o}C and a count of all pink to purple target colonies taken. Upper and lower counting limits of 10 to 150 target organisms were applied to the reported results.

Enterococci were recovered on m-ME agar (47) which also contains indoxyl-β-D-glucoside (IG). The m-ME plates were incubated for 48 hours at 41.5 ± 0.5^{o}C. The incubation time was modified from the original 24 hrs. suggested by Dufour as it allowed for a slight increase in recovery of target organisms. The addition of IG to the medium facilitates differentiation of the β-D-glucosidase enterococci from other fecal streptococci. Both target and non-target colonies were enumerated. Target colonies on m-ME were purple, white-blue to dark blue with blue haloes from degradation of the IG. Non-targets were pink to maroon non-haloed colonies. Counting range limits of 10 and 150 were also applied to these results.

<u>Pseudomonas aeruginosa</u> densities were determined using m-PA agar (46). The medium was incubated at 41.5 ± 0.5^{o}C for 48 ± 2 hrs. and a count of all flat spreading brownish-green or tan colonies obtained. Upper and lower counting limits of 10 and 150 were applied to the results.

Chamber Sample Analysis

Analysis of the pure cultures from the survival studies was also performed by membrane filtration using m-TEC for E. coli and K. pneumoniae, and m-Ent for the three species of fecal streptococci.

Sediment Weight Analysis

In addition to analyzing the samples for bacterial parameters, determination of the suspended sediment weights for both before and after agitation samples was performed by filtration of 100 mLs. of the sample onto pre-weighed Gelman filters. The filters plus sediment were dried overnight in a 37°C incubator and then weighed to obtain the weight of sediment per 100 mLs of water. Fractional sediment particle sizing was also accomplished by filtration of 100 mLs. of the sample through pre-weighed polycarbonate filters (nucleopore). The sample was filtered first through the largest pore size filter (12 µm) and the filtrate collected and subsequently passed through increasingly smaller pore sized pre-weighed filters from 10 µm to 0.2 µm. These filters were dried and weighed to determine the weight of the various size fractions per 100 mls. Samples from selected sites were also submitted for particle size determination by electron microscopy analysis. The results and discussion of the sediment particle size fractioning are presented in Appendix B of this report.

Pollution Source Determination

Sources of pollution (i.e. human or non-human) were determined by the biochemical identification of fecal streptococcus isolates obtained from upstream, source and downstream samples at each site. The identification scheme used to speciate the isolates is presented in Appendix C.

RESULTS AND DISCUSSION

The results and their discussion are presented by location. The data is further sub-divided within location under the following topics.

1. Mechanical sediment resuspension and its effect on bacterial concentrations in the water column under wet weather, dry weather, and intermediate conditions.
2. Bacterial concentration during post-rainfall periods to assess the weather dependence of the different pollution sources.
3. Naturally occurring suspended sediment levels and stream flow and their relation to bacterial concentration.
4. Types of fecal streptococci present in water column and bed sediments during dry weather.
5. In stream survival times of indicator bacteria.

Note: A detailed description of the project results is given in Appendix D. The discussion of individual locations is followed by a summary discussion which provides interlocation comparisons.

Elhart Drive (Storm Sewer)

Sediment Resuspension

Sediment

The observed level of suspended sediment (Fig. 2, Table 1) during dry weather, before mechanical sediment resuspension (MSR)

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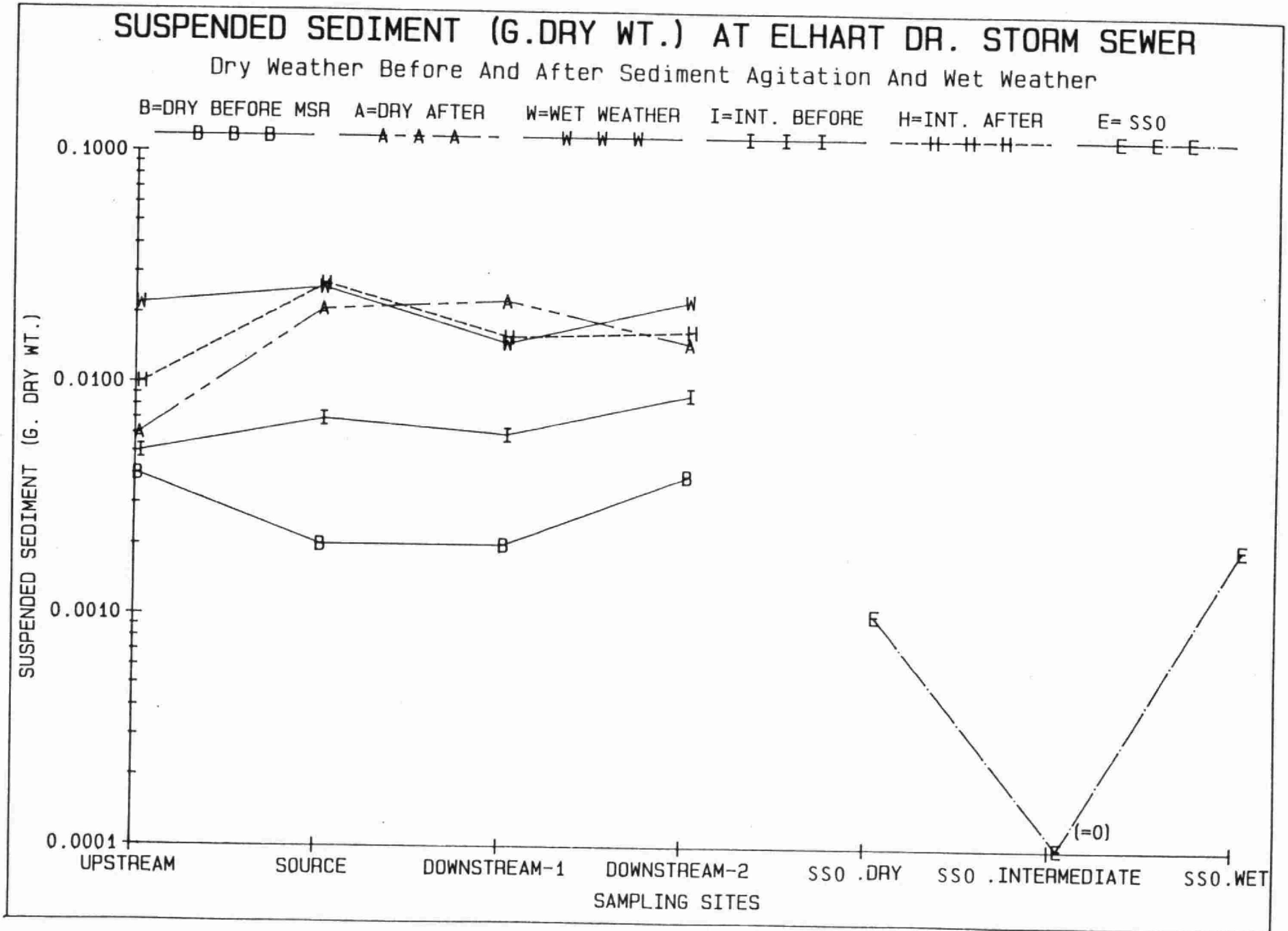

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Table 1:

Geometric mean concentrations of Fecal Indicator Bacteria, E. coli to Fecal Coliform ratios, Fecal Coliform to Fecal Streptococci Ratios and Suspended Sediment Weights During Dry and Intermediate Weather (Before and After Sediment Agitation) and Wet Weather at Elhart Drive Storm Sewer No. 250

Sampling site and weather cond.		Fecal coliforms	E. coli	Fecal Streptococci	Enterococci	P. aeruginosa	EC/FC Ratio	FC/FS Ratio	Suspended sediment (grams/100mls)
		(per 100 ml water sample)							
upstream	B	359	202	76	36	5.3	0.56	4.7	0.004
dry	A	323	240	115	52	4.7	0.74	2.8	0.006
Int.	B	1,113	864	293	123	29	0.78	3.8	0.005
	A	2,045	1,307	374	180	23	0.64	5.5	0.010
wet		4,070	2,835	1,582	806	68	0.70	2.6	0.022
source	B	364	254	81	36	5.2	0.70	4.5	0.002
dry	A	1,290	865	148	93	12.9	0.67	8.7	0.021
Int.	B	1,837	1,219	449	115	37	0.66	4.1	0.007
	A	1,765	1,286	467	174	73	0.73	3.8	0.027
wet		4,723	3,166	1,861	862	116	0.67	2.5	0.026
downstream I									
dry	B	332	331	56	42	5.3	1.0	5.9	0.002
	A	532	350	98	40	7.4	0.66	5.4	0.023
Int.	B	1,550	1,275	200	150	34	0.82	7.8	0.006
	A	3,036	2,631	375	223	77	0.87	8.1	0.016
wet		3,936	1,997	1,352	686	204	0.51	2.9	0.015
downstream II									
dry	B	337	229	86	36	4.3	0.68	3.9	0.004
	A	612	374	182	79	5.9	0.61	3.4	0.015
Int.	B	1,497	1,317	250	241	34	0.88	6.0	0.009
	A	1,657	1,237	578	384	53	0.75	2.9	0.017
wet		3,266	2,367	1,061	913	138	0.72	3.1	0.023
SSO	dry	25,847	17,692	1,034	1,585	14.2	0.68	25.0	0.001
	Int	6,791	4,135	1,177	989	78	0.61	5.8	0.001
	wet	13,624	8,009	2,209	1,694	132	0.59	6.2	0.002

decreased at source and the first downstream site (DN1) thus suggesting that sediment deposition was occurring between the upstream site (UP) and DN1. MSR increased suspended sediment levels demonstrating that sediment (SED) deposition was in fact occurring at all sites, but was greatest in the area of source and DN1, where SED concentrations were increased ten-fold. The least amount of sedimentation appears to be occurring at UP. The river bends at DN1 which may cause a slight decrease in flow or result in back eddies which can cause increased sedimentation.

The sediment deposits at source and DN1 are likely a combination of SED from upstream and the storm sewer input. This may also be true of the second downstream site (DN2), but since the water column SED levels at this site, before MSR, are similar to UP, even though net SED deposition appears to occur at all 3 sites, some of the SED impacting on DN2 could come from resuspension of sediments occurring below DN1. In fact there is probably active sedimentation and SED resuspension occurring at all sites. The dynamics of the system will be governed by the relative rate of the two actions, both of which will be governed by the hydrology and geomorphology of the area (31). Resuspension could be the main cause of the increase in suspended sediment levels at DN2 (before MSR) as the SED concentrations in the effluent are lower than in the river.

The greater flow and inputs from diffuse and point sources to the river during wet weather (storm event to 24 hrs. following) increase the concentration of suspended sediments (S.SED)

in the water column. The slight decrease in S.SED noted at DN1 may be a further indication of the tendency for sedimentation at this site or it may be due to dilution from the impact of the increased storm sewer outfall (SSO) flow which has a lower S.SED concentration than the river. The position of the source station out in the river relative to the SSO could reduce its effect till further downstream. The following section examining bacterial levels suggests, however, that some impact from the SSO flow occurs at source and that sedimentation is the likely cause of the decrease in S.SED at DN1 during wet weather.

The increase in S.SED at DN2 is most likely the result of SED resuspension and any impact of the flow from the SSO at DN1 could be masked downstream by further instream mixing.

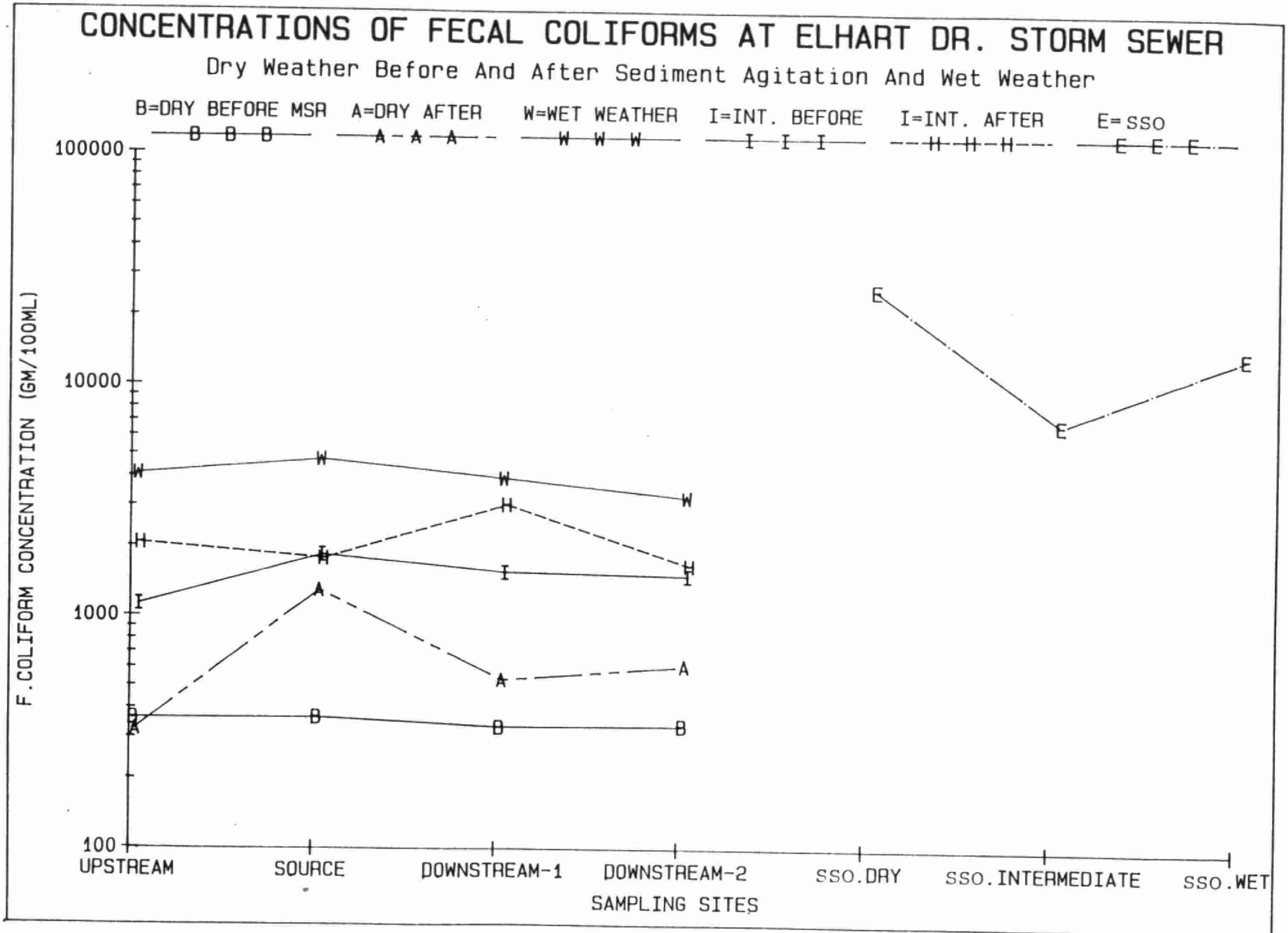
Unfortunately due to the increased flow in the river during storm events, it was not possible to enter the river and use MSR to determine if any sediment deposition was occurring.

Intermediate weather conditions (24-48 hrs. following storm event) still showed the impact of increased sediment loading caused by wet weather, but at a reduced level.. The fact that the S.SED levels at UP are only slightly above those occurring during dry weather and that the S.SED in the flow from the SSO was below detection limits, while S.SED at the other sites was raised, is again indicative of ongoing sediment resuspension. The increase in S.SED levels at UP and source by MSR beyond those achieved during dry weather suggests that as the storm flow decreases, sedimentation increases (27,31) resulting in greater

SED deposits. As the river returns to dry weather flow MSR results suggest a decrease in SED deposits at all sites except DN1. This would appear to indicate that resuspension exceeds deposition until equilibrium is reached. At DN1 whatever SED is undergoing deposition during wet weather or the change to intermediate conditions does not appear to remain but is moved downstream. This could account for the increased levels of SED at DN2. As conditions in the river continue to stabilize to dry weather then SED deposits at DN1 are rebuilt.

Bacteria

The concentrations of the fecal indicator bacteria (FIB) in the SSO (Fig. 3-7) have little impact on their levels in the Humber River during dry weather. The heavy bacterial loadings to the location from upstream obscure the input despite the effluent concentrations being higher than those in the river. The only parameter that appears to react, in the water column, to the effluent input is E. coli (Fig. 4), which shows a small increase in levels at source and DN1. The increase of fecal streptococci (FS) (Fig. 5) at DN2 is possibly due to sediment resuspension rather than the effluent since no effect is apparent on Enterococci (ENT) (Fig. 6) even though effluent concentrations were higher. It is also possible that the SSO has an impact on FIB levels that is hidden since without the input FIB levels might have shown an overall reduction through the location due to sedimentation and die-off.



CONCENTRATIONS OF FECAL COLIFORMS AT ELHART DR. STORM SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
I=INT. AFTER
E=SSO
F.COLIFORM CONCENTRATION (GM/100ML)
100000
10000
1000
100
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SSO.DRY
SSO.INTERMEDIATE
SSO.WET
SAMPLING SITES

HARRIS-A2

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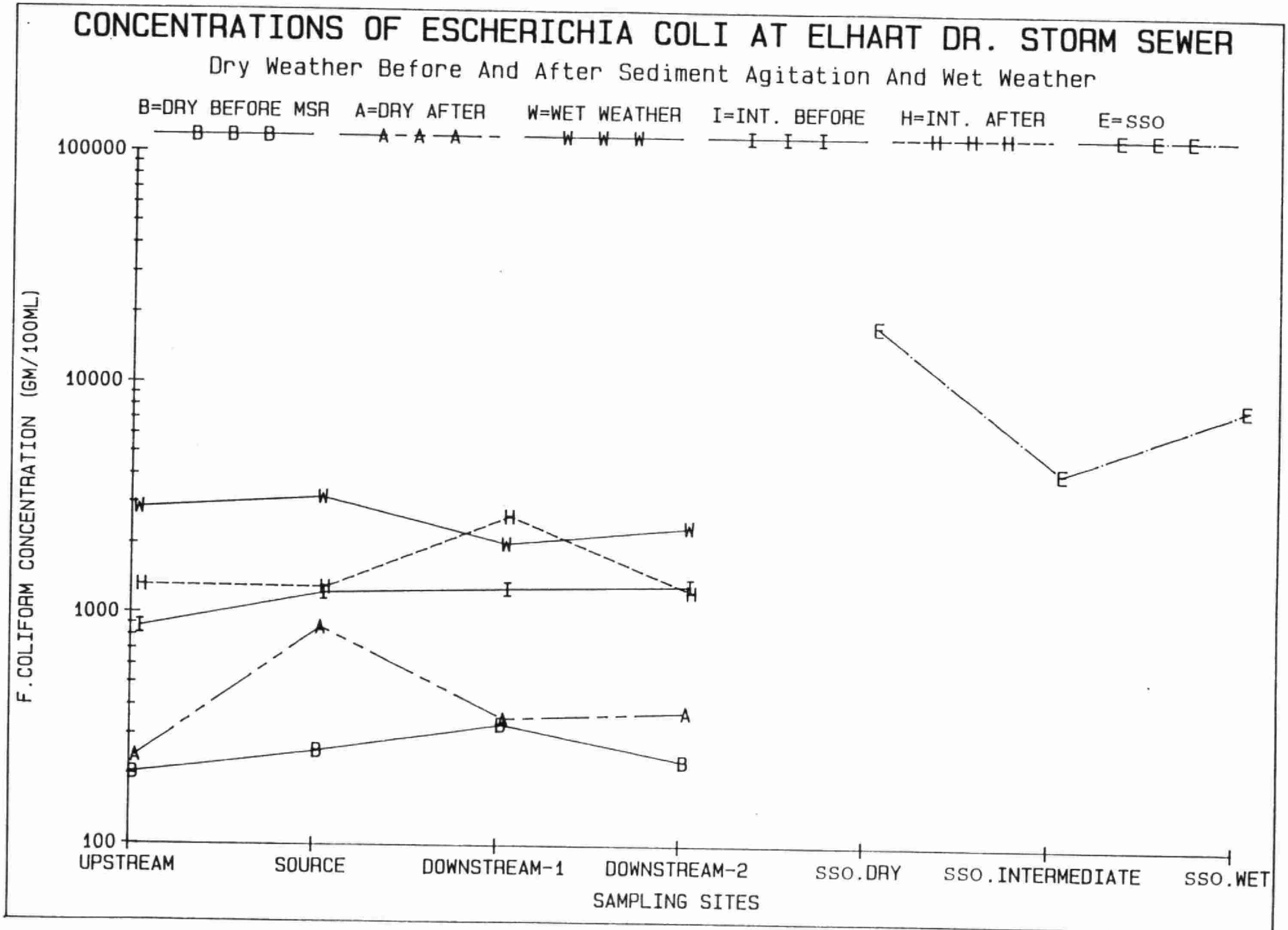
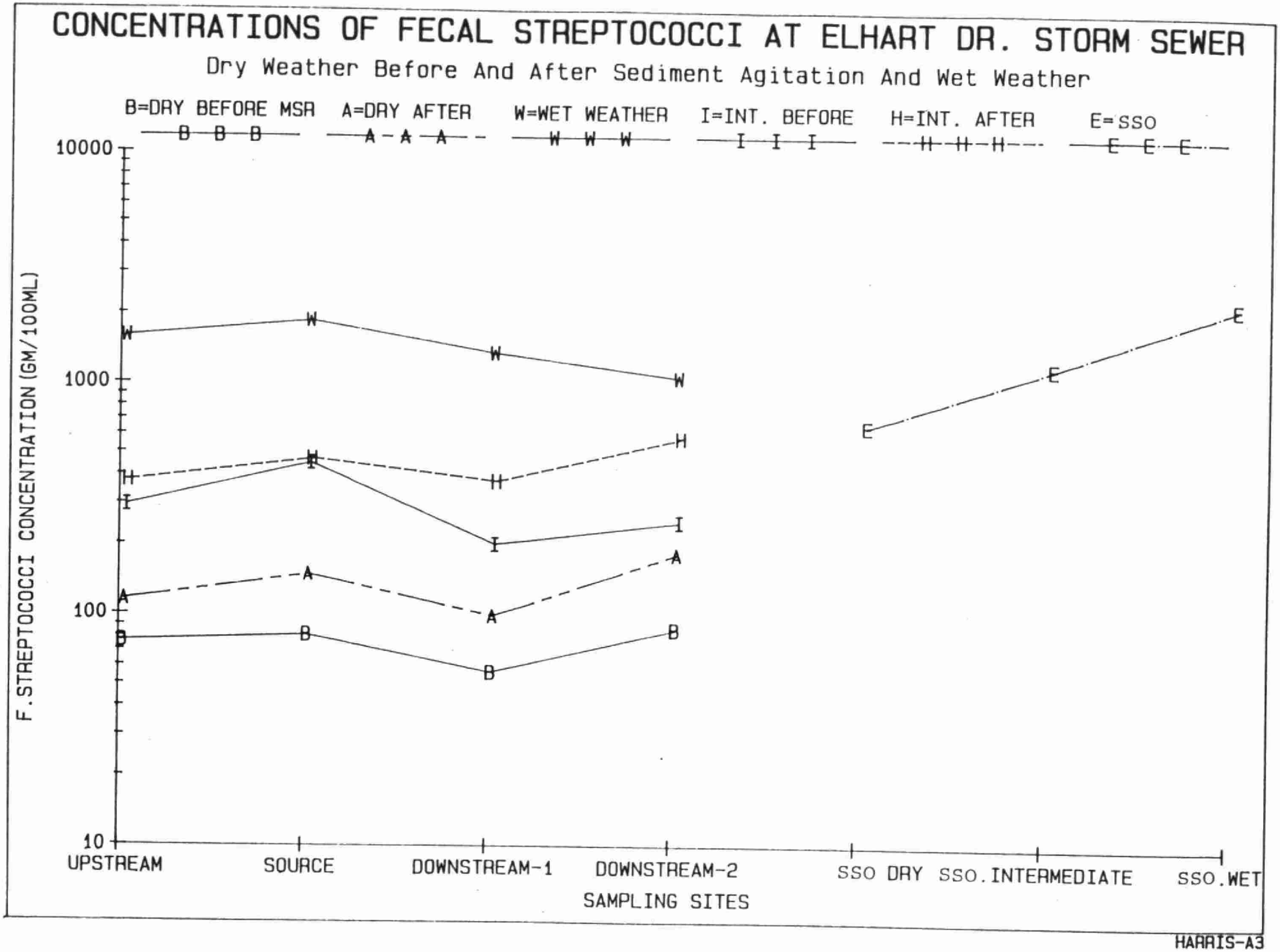


HARRIS-A1


CONCENTRATIONS OF FECAL STREPTOCOCCI AT ELHART DR. STORM SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=SSO
F.STREPTOCOCCI CONCENTRATION (GM/100ML)
10000
1000
100
10
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SSO DRY
SSO.INTERMEDIATE
SSO.WET
SAMPLING SITES
HARRIS-A3

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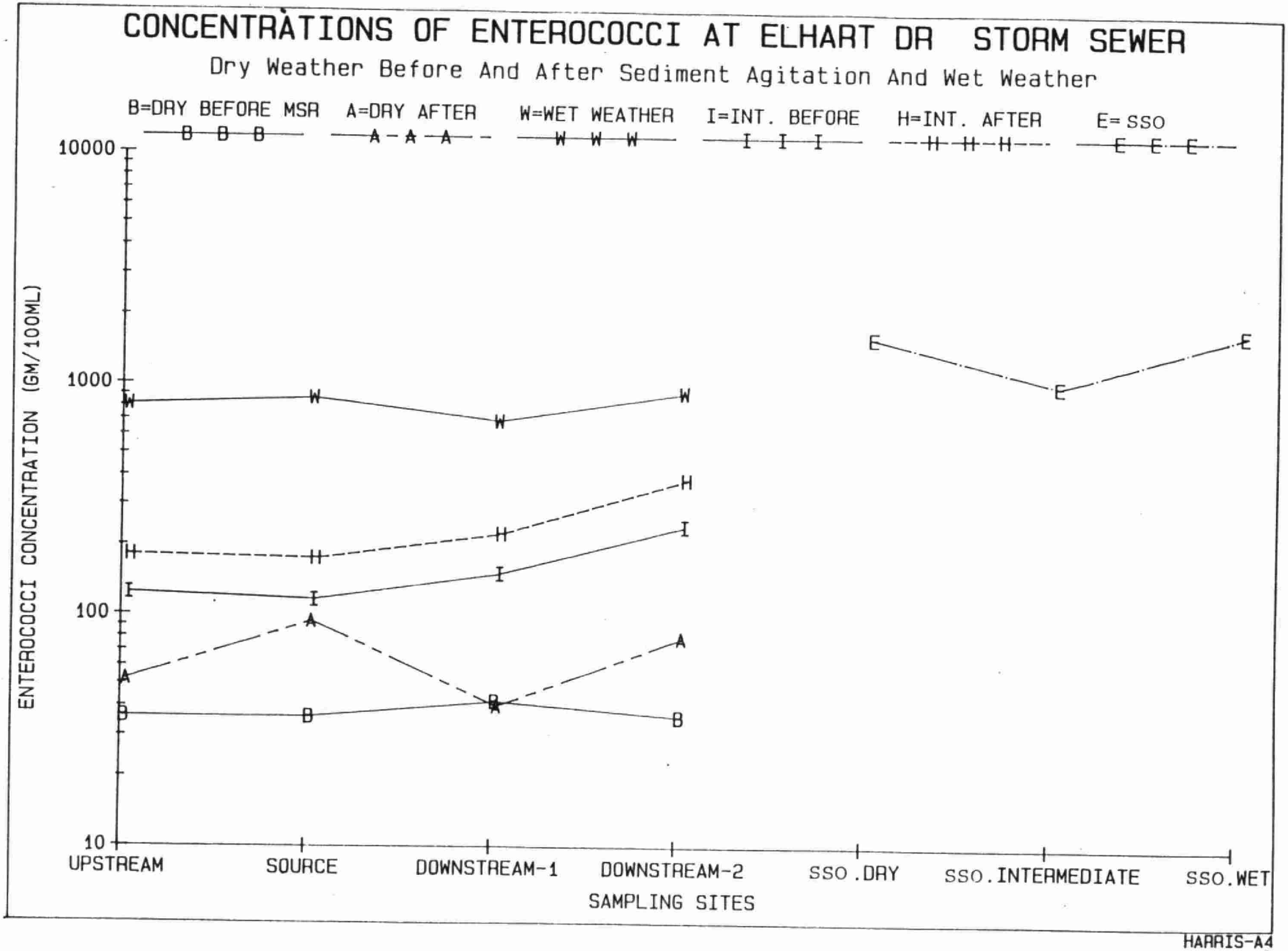
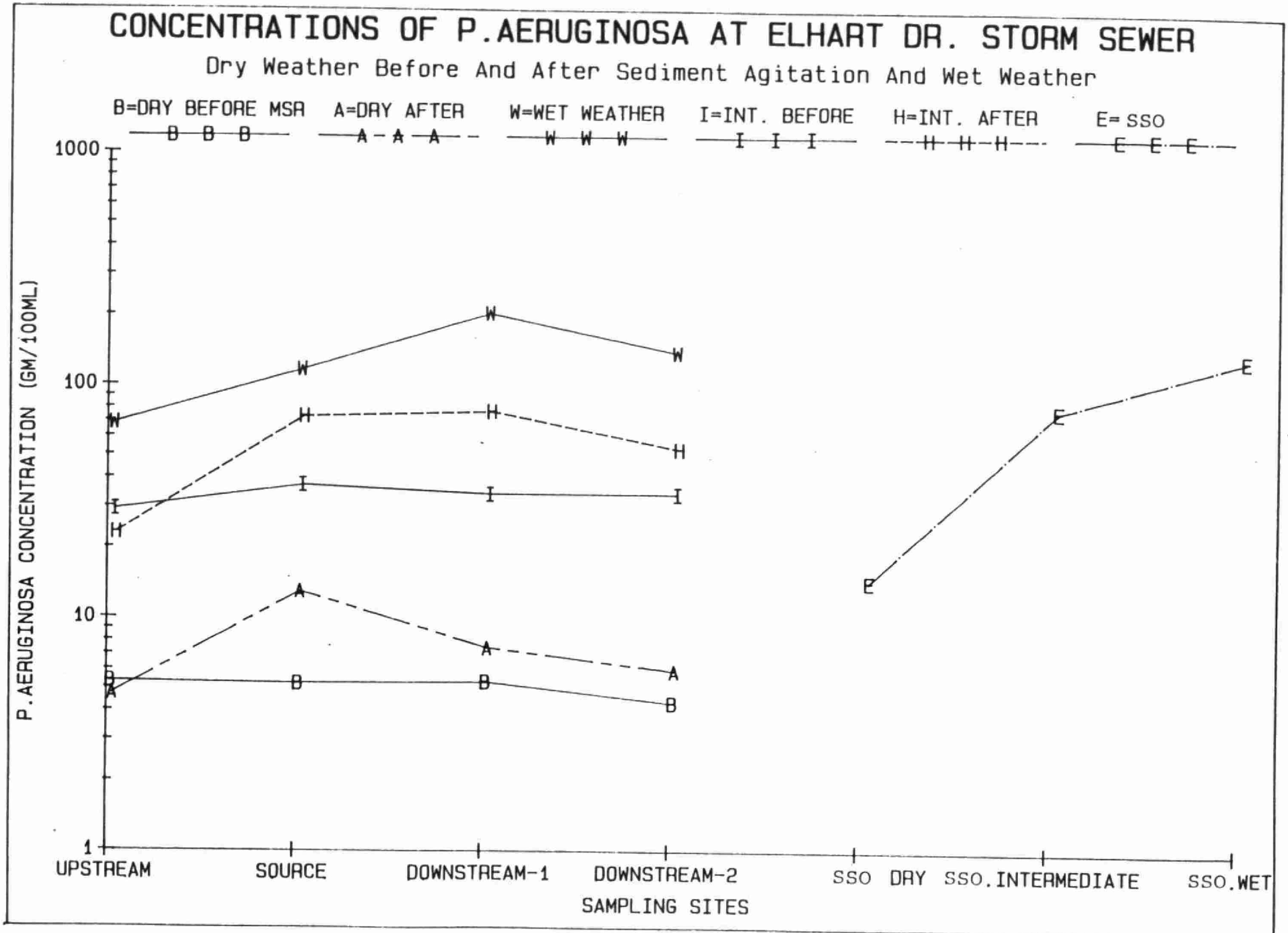


CONCENTRATIONS OF ENTEROCOCCI AT ELHART DR STORM SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E= SSO
10000
1000
100
10
ENTEROCOCCI CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SSO.DRY
SSO.INTERMEDIATE
SSO.WET
SAMPLING SITES
HARRIS-A4


CONCENTRATIONS OF P.AERUGINOSA AT ELHART DR. STORM SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E= SSO
P.AERUGINOSA CONCENTRATION (GM/100ML)
1000
100
10
1
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SSO DRY
SSO.INTERMEDIATE
SSO.WET
SAMPLING SITES

HARRIS-A5

The use of MSR provides a more dramatic indication of the presence of a contaminated input. This is particularly true at source where there is an increased sediment build-up of all FIB except FS. Although a comparison of the effect of MSR on fecal coliforms (FC), E. coli (EC) and Pseudomonas aeruginosa (PSA) (Fig. 7) at UP (negligible), DN1 and DN2 suggest that the SSO might be having some impact on the increased levels downstream, the same comparison for FS and ENT indicated that some of the deposition is undoubtedly from upstream of these sites, since there is an impact at UP. The relatively greater decrease in MSR effect for EC and ENT in comparison to the less specific FC and FS may be a further indication of deposition of upstream sediments at DN1. If the deposited sediments were from upstream then the fecal contamination carried would be older and relative levels of EC to FC and ENT to FS would be reduced. This is especially true of EC to FC ratios since E. coli tends to die-off more rapidly than other fecal coliforms (36,41).

The increased upstream contaminant loadings to the Humber River during wet weather again result in FIB concentrations entering the site that almost overpower any effect of increased loadings from the Elhart Drive SSO. There are only slight increases at source for FC, EC, FS and ENT. PSA was the only parameter that not only increased at source but again at DN1 and since S.SED was not at higher levels at these sites, the SSO is the most likely cause. The almost tenfold increase in effluent concentrations of PSA during wet weather (FC and EC decreased,

ENT showed little change and FS doubled) could be the reason for this effect. The large increase in PSA levels in the storm water may indicate that this organism survives well in the sewer and may accumulate during dry weather or even grow.

During intermediate weather conditions the SSO continues to have only a small impact on levels of FIB in the river, in most cases only at source. The effect on ENT levels is delayed until DN1 and DN2, however, some of this increase at least at DN2, may be from resuspended sediments as FS also increases.

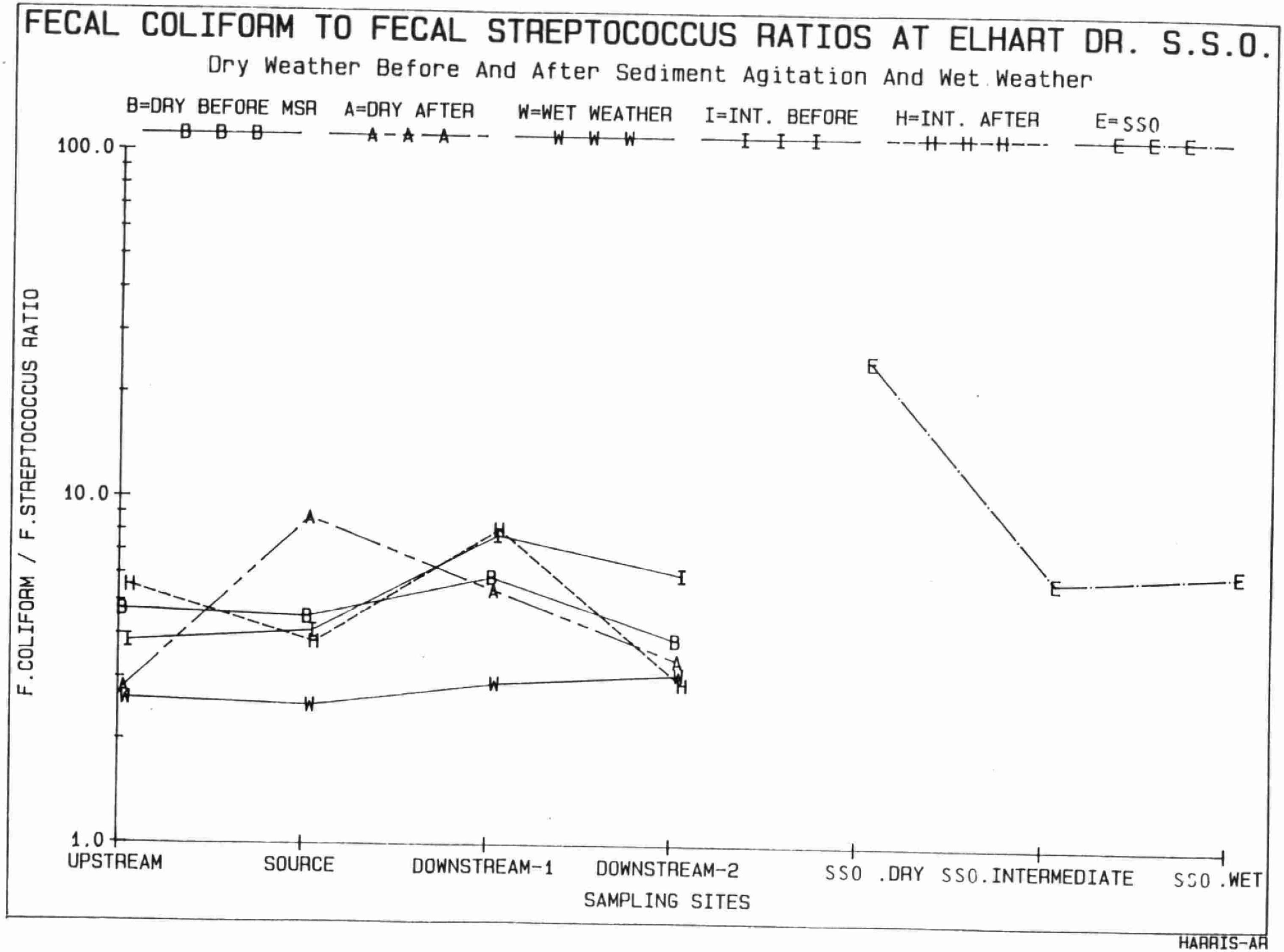
The effect of MSR on FIB densities during dry weather demonstrated that the deposition of contaminated sediments was occurring at the Elhart Drive location. The deposits are undoubtedly a mixture of sediments from both upstream and the SSO but the relative proportion can not be determined from this study. The effect of this deposition on the accumulation of bacteria varied from parameter to parameter. This would be due to a number of factors which would differ from bacteria to bacteria such as die-off rates, ability to adsorb to particles and the relative concentrations between upstream waters and SSO. The FIB which appeared to be affected most by SSO were FC and EC and to a smaller extent ENT and PSA. The increases in FS caused by MSR basically follow the same site-to-site fluctuations as levels before MSR and thus are probably more reflective of upstream contamination.

<u>FC/FS</u>

The FC/FS ratio of 25 in the SSO flow during dry weather is quite high (Fig. 8, Table 1) and in the range that could indicate the presence of human fecal contamination (13, 48, P. Seyfried, E. Harris and M. Young 1986, unpublished). A small impact from this input can be seen on the water column at DN1 but is much more apparent at source following MSR. The low instream FC/FS ratios, which are undoubtedly the result of mixed input types from various distances upstream, almost completely masked any effect of the SSO.

The overwhelming loading from a variety of sources upstream effectively obliterates any potential effect of the SSO during wet weather.

During intermediate conditions the FC/FS increase noted at DN1 before and after MSR seems unusual because of the reduced FC/FS ratio in the SSO. It is quite possible, however, that resuspension and/or other means of sediment transport have affected sediments in the source area and may also be contributing to the observed increase. The increased FC/FS ratio at UP, following MSR, indicates that the deposited sediment may have a higher content of fecal contamination than during dry weather. At source, however, which has a higher level of SED deposition, MSR has the reverse effect on FC/FS, although the change is very small (i.e. 4.1 to 3.8). This would suggest slightly less fecal pollution impact on this site. The cause could be a general downstream shift in bed sediments during wet


FECAL COLIFORM TO FECAL STREPTOCOCCUS RATIOS AT ELHART DR. S.S.O.
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=SSO
100.0
10.0
1.0
F.COLIFORM / F.STREPTOCOCCUS RATIO
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SSO .DRY
SSO.INTERMEDIATE
SSO .WET
SAMPLING SITES
HARRIS-AR

weather and/or an increase in the accumulation of sediments incorporating more upstream sediments that contain either older or less fecal material and thus have higher FS densities.

Post-Rainfall Bacterial (EC/FC) Quality

The original source of *E. coli* is the feces of warm blooded animals where it is the predominant coliform (P. Seyfried, E. Harris, M. Young, 1986 unpublished). While it will survive for a short time in the aquatic environment its numbers will decrease with increasing distance from input due to die-off and sedimentation. The fecal coliform group of bacteria includes not just *E. coli* but other bacteria i.e. *Klebsiella* sp., *Enterobacter* sp. and *Citrobacter* sp., that are also found extensively in natural environments. This increases the multiplicity of potential "total" FC sources and with their better survival times will tend to slow the rate of decline of the FC recoveries in comparison to *E. coli* alone. Thus a trend of decreasing EC/FC ratios would suggest either a) increasing distance from or b) age of or c) dilution by non-fecal inputs, of the original fecal inputs.

The examination of post-rainfall bacterial fluctuations was not part of the original study but was suggested during the data manipulation process (J. Macdonald - personal communication). Thus only a limited amount of data was available.

The almost daily changes in the EC/FC ratio (Table 2) and the generally small magnitude of the change (±.1) suggest that, on its own, day to day fluctuations in EC/FC ratios during post-

Table 2:

Escherichia Coli to Fecal Coliform Ratios during Post-Rainfall Period at Elhart Drive Storm Sewer

Site	Number of Days Following Rainfall 0	1	2	3	4
UB	4645 7001 (0.66)	864 1113 (0.78)	147 361 (0.41)	249 355 (0.70)	780 1260 (0.62)
UA		1307 2045 (0.64)	351 483 (0.73)	186* 247* (0.75)	1500 1700 (0.88)
SB	4573 7076 (0.65)	1219 1837 (0.66)	304 387 (0.79)	226 349 0.65)	880 1190 (0.74)
SA		1286 1695 (0.76)	951 1426 (0.67)	812 1206 (0.67)	1200 1200 (1.0)
DN1B	2828 6387 (0.44)	1275 1551 (0.82)	219 339 (0.64)	216 343 (0.63)	1200 1500 (0.81)
DN1A		2631 3036 (0.87)	427 597 (0.72)	429 651 (0.66)	1000 1000 (1.0)
DN2B	3469 5104 (0.68)	1317 1498 (0.88)	199 333 (0.60)	263 366 (0.72)	1180 1460 (0.81)
DN2A		1237 1657 (0.75)	277 534 (0.52)	466 759 (0.61)	1030 1520 (0.68)
SSO	22797 29795 (0.77)	4135 6791 (0.61)	10100 35537 (0.28)	17097 20904 (0.82)	3100 5000 (0.62)

E. coli / F. Coliforms (Ratio) *approximate value

rainfall periods is of limited use. It may be that more frequent sampling over a number of wet weather events for a period longer than fours days is required. The sampling scenario would need daily sampling prior to a storm followed by an increased sampling frequency until concentrations returned to normal dry weather conditions. If this type of intensive survey can not be carried out then the EC/FC ratio of the geometric mean values of several pieces of data obtained under the different weather conditions should provide an indicator of the relative "freshness" of the fecal contamination.

The levels of FC and EC and the EC to FC ratio in the water column at the upstream site (UB) (Table 2) are suggestive of more recent fecal input during wet (Day 0) and intermediate weather (Day 1) than dry. The water column levels drastically drop from day 1 to day 2 suggesting a washout effect after the storm. However both FC and EC levels in the water column increase by day 4 indicating subsequent dry weather loadings to the river after a storm washout. The EC to FC ratio is still somewhat lower on day 4 than during wet and intermediate weather and thus may be reflecting distant upstream inputs or dilution by non-fecal inputs. The relative levels of both FC and EC in resuspended sediments (UA) drop from day 1 to day 2, but increase by day 4, indicating that dry weather loading to the sediments is occurring. The increase in EC to FC ratios in the resuspended sediments from day 1 to day 4 (0.6 to 0.9) would indicate that the fecal pollution loadings during dry weather are very recent

and perhaps reflected better in the sediments than in the water column due to ongoing deposition.

The general trend in FIB counts occurring at the upstream site is also noted at source, DN1 and DN2 during the post-rainfall period. The high EC to FC ratios (1.0) in the resuspended sediments at source and DN1 on day 4 again suggest recent dry weather loadings to the sediments most likely due to combined inputs from the SSO and from upstream. At DN2 more recent fecal inputs appear to be transferred to the sediment during intermediate conditions but not during dry weather.

The SSO FIB levels and EC to FC ratios do not follow the same trends noted instream. Any possible impact of this fluctuation on instream quality would require a much more intensive study to resolve. The geometric mean levels (Table I) suggest the affect may be greater during dry weather than intermediate or wet.

The SSO EC to FC ratios (Table 1) tend to be lower than those instream, except during dry weather where the ratio is equal to that of source (0.7); however, this input is still a likely contribution of "recent" fecal inputs during dry and intermediate weather to the source and downstream sites.

During dry weather, MSR demonstrates that there is no difference in the proportional amount of "recent" fecal contamination in the sediment as indicated by the EC to FC ratios. Again this does not contradict the evidence of increased sediment, FC and EC concentrations at source (Table 1) since

agitating the bed sediment will resuspend material which has accumulated over time and thus be of varying age with different EC to FC levels. In an area of deposition, which the source site appears to be, most of the sediment will be aged. Even the ratios in the effluent are indicative of the fact that the fecal inputs occurred somewhere up the sewer line.

The EC to FC ratios before and after MSR during intermediate weather (Table 1), show that more recent impacts are occurring. The SSO is undoubtedly having some effect, but the EC/FC ratios at UP (0.8) suggests that recent fecal pollution from upstream is being carried to the downstream sites.

A comparison of the changes in EC/FC and FC/FS within and between sites demonstrates a lack of any apparent relationship. This is not surprising since the ratios are reliant upon different groups of bacteria with different die-off rates and some differences in source. An example of these differences was found in an earlier University of Toronto study (P. Seyfried, E. Harris, and M. Young, 1986, unpublished). The relative EC to FC levels in feces varied very little between animals usually being at or near 1, while the relative FC to FS densities could vary considerably.

It is possible that EC/FC is a better indicator of how recent pollution is at a given site while FC/FS may indicate the fluctuations in level of fecal pollution.

Thus it would be possible to have EC/FC remain the same (no major change in recentness of fecal input) or decrease (older

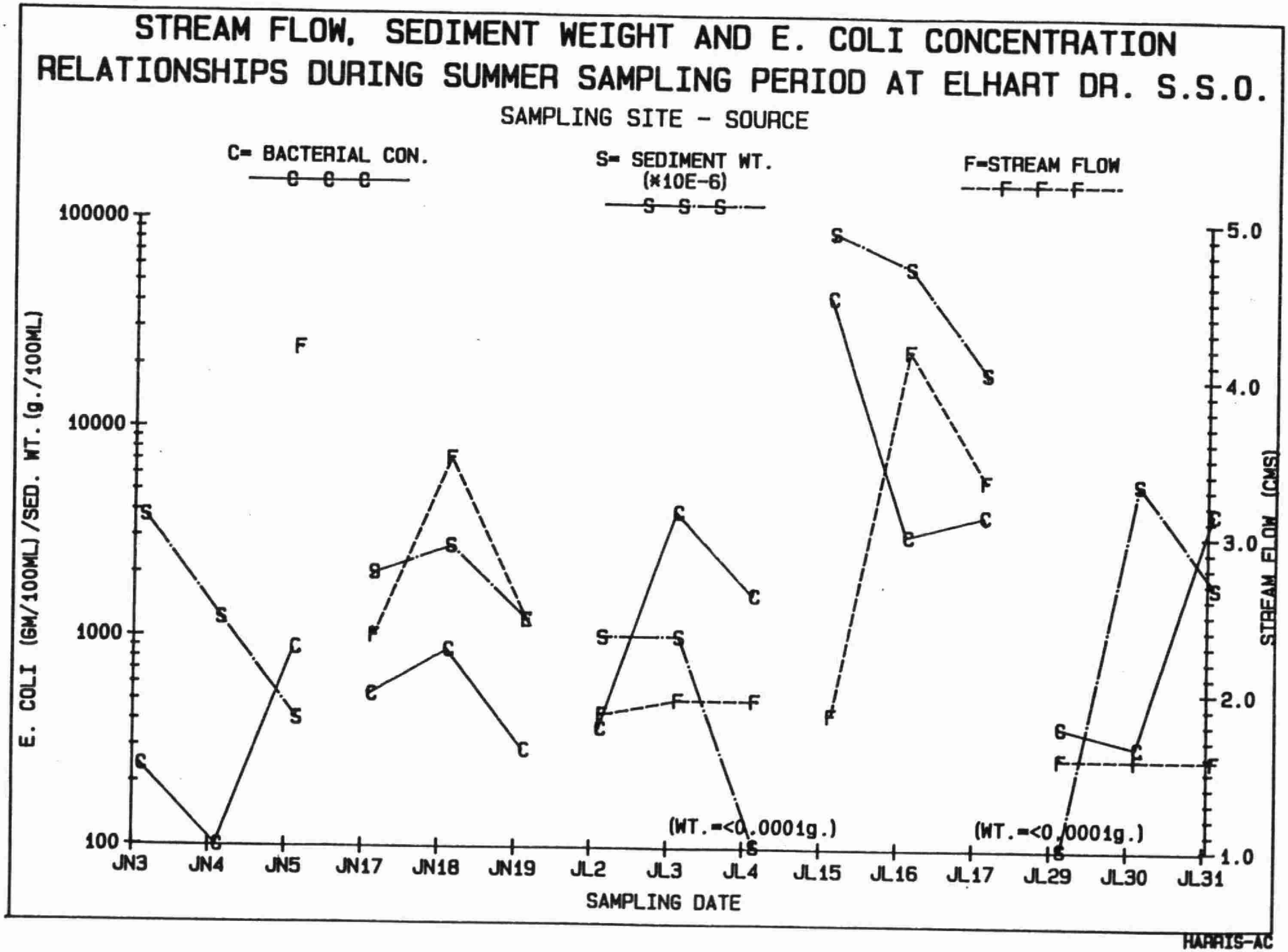
fecal material) while FC/FS increased (inputs from a source containing fecal inputs increases). As indicated before, this type of theory would require further study.

Natural Environmental Phenomena and Bacterial Concentrations

An examination of the daily changes in flow, SED and bacterial concentrations at source for each survey (Fig. 9A and 9B) demonstrates a high degree of variability with no obvious relationships. The graphs of daily flow (Fig. 10A) and rainfall (Fig. 10B), obtained at established monitoring stations, show that increases in flow in the lower Humber can be related to storm events and that there can be considerable variability in flow in one day. This type of detail is missed in short term surveys with sampling once a day. A study that was designed to elucidate relationships between parameters such as flow would require much greater sampling intensity that would include sampling during the storm peak periods.

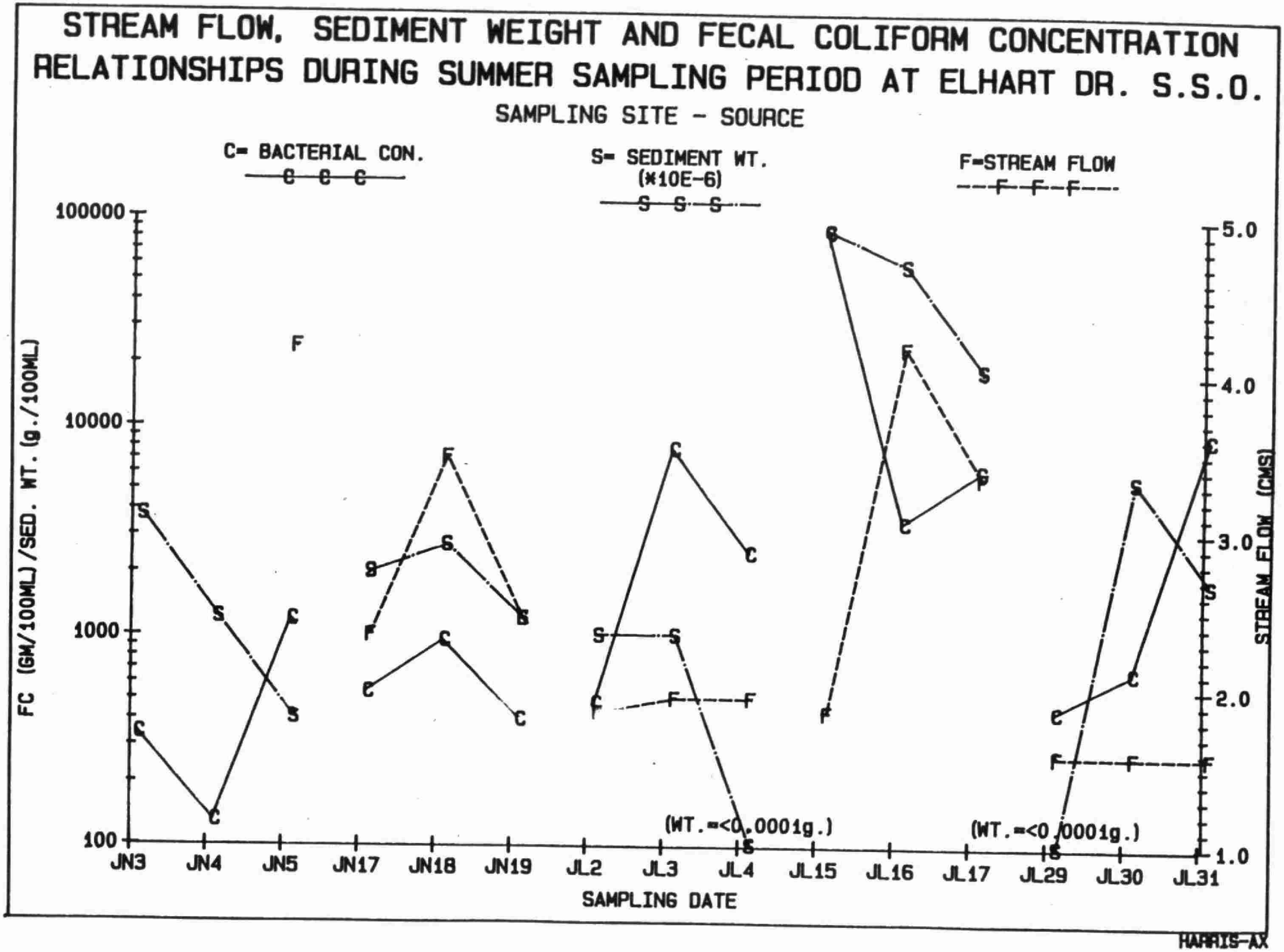
By determining the relationships of the individual surveys (Fig. 9A and 9B) to the storm events occurring in the lower Humber River (Fig. 10B) the general type of impact possible can be seen. Flow increases and then decreases as a storm event passes (e.g. July 17-19 and July 15-17). The peak in flow was missed at source during the third survey (July 2-4) but this could be due to the limited sampling and daily variability. The graph of flow from the main gauging station (Fig. 10A) did show that a storm effect did occur.

Figure 9A:



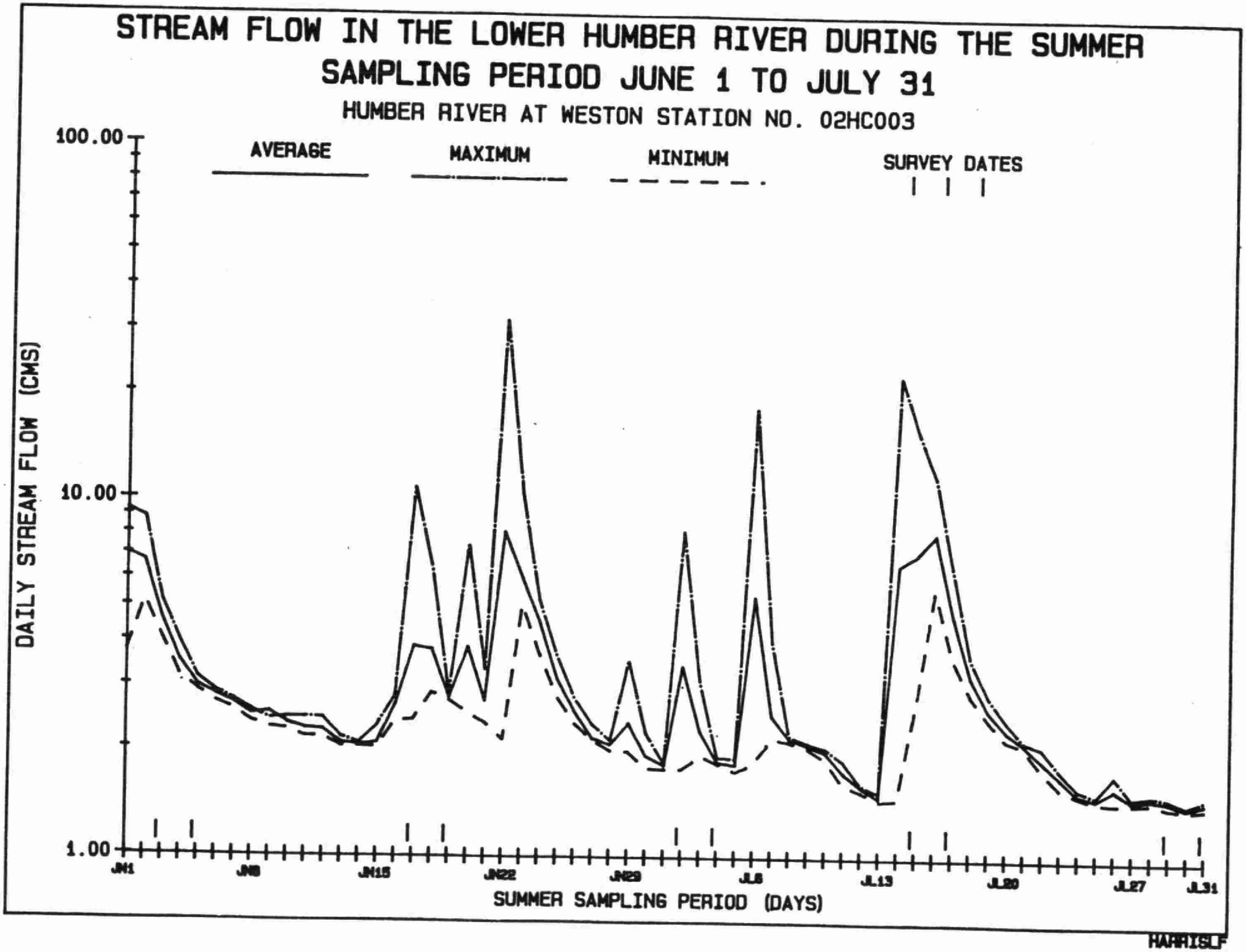
STREAM FLOW, SEDIMENT WEIGHT AND E. COLI CONCENTRATION
RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT ELHART DR. S.S.O.
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT.
(*10E-6)
F=STREAM FLOW
E. COLI (GM/100ML)/SED. WT. (g./100ML)
STREAM FLOW (CMS)
100000
10000
1000
100
5.0
4.0
3.0
2.0
1.0
(WT.=<0.0001g.)
(WT.=<0.0001g.)
JN3
JN4
JN5
JN17
JN18
JN19
JL2
JL3
JL4
JL15
JL16
JL17
JL29
JL30
JL31
SAMPLING DATE
HARRIS-AC

Figure 9B:

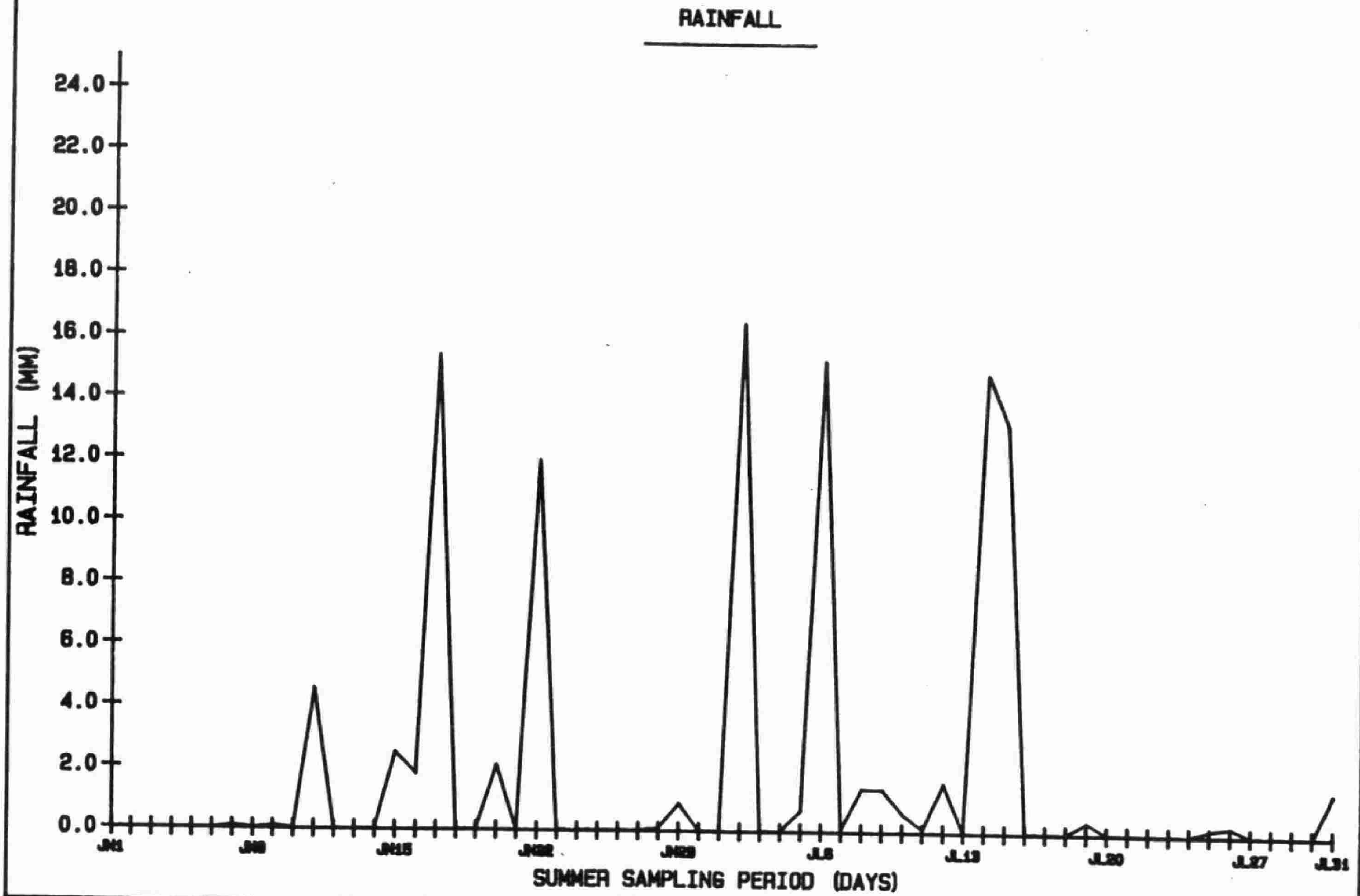


STREAM FLOW, SEDIMENT WEIGHT AND FECAL COLIFORM CONCENTRATION RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT ELHART DR. S.S.O.
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT. (*10E-6)
F=STREAM FLOW
FC (GM/100ML)/SED. WT. (g./100ML)
100000
10000
1000
100
STREAM FLOW (CMS)
5.0
4.0
3.0
2.0
1.0
(WT.=<0.0001g.)
(WT.=<0.0001g.)
JN3
JN4
JN5
JN17
JN18
JN19
JL2
JL3
JL4
JL15
JL16
JL17
JL29
JL30
JL31
SAMPLING DATE
HARRIS-AX

Figure 10A:


STREAM FLOW IN THE LOWER HUMBER RIVER DURING THE SUMMER SAMPLING PERIOD JUNE 1 TO JULY 31
HUMBER RIVER AT WESTON STATION NO. 02HC003
AVERAGE
MAXIMUM
MINIMUM
SURVEY DATES
100.00
10.00
1.00
DAILY STREAM FLOW (CMS)
SUMMER SAMPLING PERIOD (DAYS)
HARRISLF

PRECIPITATION IN THE LOWER HUMBER REGION DURING THE SUMMER SAMPLING PERIOD JUNE 1 TO JULY 31



HARRISLP

The increase in flow which is caused by point source and diffuse run-off brings along with it increased bacterial and sediment inputs and once flow becomes sufficient, inputs from bed sediment resuspension will also occur. As the storm and flows subside the reverse effects take hold and sediment and bacterial levels drop. This scenario appears to be affecting the second and third surveys (June 17-19 and July 2-4 respectively). It is also possible that the effects of a storm would eventually reverse themselves and begin to cause some dilution as the majority of dry weather accumulated contaminants were washed through the system. This could lead to a decrease in SED and bacteria before flow decreased, such as occurred during the fourth survey.

The increases in bacteria and sediment during the first (June 3-5) and fifth (July 29-31) survey do not appear to be related to storm events and may be due to sporadic inputs from the Elhart Drive SSO and/or other inputs upstream. A more detailed survey meant to study this type of phenomenon would be able to determine if the SSO was the causative agent in these cases.

The regression analyses with sediment weight (Table 3) indicates that suspended sediment in this location is primarily affected by sources upstream except at DN1. DN1 could be showing the impact of the SSO while its effect appears to be dissipating by DN2. This also appears to be the case for the bacterial parameters, particularly EC.

Table 3:

Correlation Coefficients of Suspended Sediment Weights (Before Sediment Agitation) with Fecal Coliform, Escherichia coli Counts and Flow Rate at Elhart Drive Storm Sewer

Sediment Weight	Sediment Weight: Upstream	Source	Downstream I	Downstream II
Upstream	+ 1.00	+ 0.93	+ 0.29	+ 0.70
Source		+ 1.00	+ 0.62	+ 0.91
Downstream I			+ 1.00	+ 0.88
Downstream II				+ 1.00
Fecal coliforms				
Upstream	+ 0.70	+ 0.74	+ 0.36	+ 0.65
Source	+ 0.68	+ 0.68	+ 0.25	+ 0.55
Downstream I	+ 0.68	+ 0.68	+ 0.26	+ 0.57
Downstream II	+ 0.63	+ 0.61	+ 0.16	+ 0.47
E. coli				
Upstream	+ 0.68	+ 0.76	+ 0.43	+ 0.70
Source	+ 0.70	+ 0.71	+ 0.31	+ 0.60
Downstream I	+ 0.39	+ 0.49	+ 0.38	+ 0.53
Downstream II	+ 0.57	+ 0.58	+ 0.20	+ 0.48
Flow rate	+ 0.10	+ 0.33	+ 0.66	+ 0.54

The regression analyses run on FC and EC (Table 4) shows a good correlation within sites with a decrease in any existing relationships over distance between sites. This basically indicates that at any given site similar environmental factors, inputs, etc. are effecting both FC and EC and the factors acting upon these bacterial concentrations change to some degree from site to site.

The lack of correlation between flow and the other parameters, except SED at DN1 and FC at source, indicated, as one would expect, that the flow at a specific site is only one of the factors affecting levels of SED and FIB.

Streptococcus Populations

The high proportion of *S. faecalis* var zymogenes and *S. faecium* var casseliflavus in the water column at UP (Table 5) indicates that any human fecal contamination that may be present is masked by non-human fecal and non-fecal inputs. The changes in proportional isolation of streptococci brought on by MSR still reflect mixed inputs dominated by non-human inputs. During wet weather the proportional increase in *S. faecalis* var faecalis and *S. faecium* var faecium suggests that although the loadings to the system are dominated by non-fecal and "old" accumulations there is more evidence of human fecal input within the existing fecal pollution load. The increase in *S. durans* along with *S. faecium* can also be in part due to human fecal inputs.

Table 4:

Correlation Coefficients of Fecal Coliform, Escherichia coli
Counts and Flow Rate at
Elhart Drive Storm Sewer

	Fecal Coliforms			
E. coli	Upstream	Source	Downstream I	Downstream II
Upstream	+ 0.96	+ 0.84	+ 0.82	+ 0.57
Source	+ 0.90	+ 0.97	+ 0.87	+ 0.77
Downstream I	+ 0.89	+ 0.88	+ 0.97	+ 0.77
Downstream II	+ 0.59	+ 0.71	+ 0.74	+ 0.95
Fecal coliforms				
Upstream	+ 1.00	+ 0.91	+ 0.90	+ 0.67
Source		+ 1.00	+ 0.92	+ 0.80
Downstream I			+ 1.00	+ 0.82
Downstream II				+ 1.00
Flow rate	+ 0.10	+ 0.65	+ 0.004	- 0.10
E. coli	E. coli			
Upstream	+ 1.00	+ 0.87	+ 0.81	+ 0.49
Source		+ 1.00	+ 0.86	+ 0.69
Downstream I			+ 1.00	+ 0.72
Downstream II				+ 1.00
Flow rate	+ 0.23	+ 0.14	+ 0.25	- 0.01

Table 5:

Fecal Streptococcus Populations at Elhart Drive Storm Sewer Under Wet and Dry Weather Conditions

Site and cond.		Total Isolates	S.faecalis faecalis	S.faecalis liquefaciens	S.faecalis zymogenes	S.faecium	S. faecium casseliflavus	S.durans	S.bovis	S.avium	Fecal Strep	Non-fecal streptococci	Aerococcus
UPSTRM	Dry Before	20	-	-	2(10.0)	1(5.0)	13(65.0)	4(20.0)	-	-	-	-	-
	Dry After	18	-	-	1(5.6)	1(5.6)	9(50.0)	2(11.0)	-	-	1(5.6)	-	-
	Wet	33	1(3.0)	12(36.4)	-	6(18.2)	5(15.2)	6(18.2)	-	-	2(6.1)	1(3.0)	-
SOURCE	Dry Before	20	-	-	3(15.0)	2(10.0)	12(60.0)	3(15.0)	-	-	-	-	-
	Dry After	23	-	4(17.0)	6(26.0)	-	8(35.0)	3(13.0)	-	-	-	2(8.7)	-
	Wet	39	7(17.9)	4(10.3)	-	12(30.8)	6(15.4)	9(23.1)	-	-	1(2.6)	-	-
DOWNSTRM	Dry Before	12	-	-	-	-	6(50.0)	5(42.0)	-	-	-	1(8.3)	-
	Dry After	12	-	3(25.0)	1(8.3)	2(17.0)	4(33.0)	2(17.0)	-	-	-	-	-
	Wet	28	3(10.7)	3(10.7)	-	11(39.3)	3(10.7)	7(25.0)	-	-	1(3.6)	-	-
SSO	Dry Before	20	-	3(15.0)	-	1(5.0)	10(50.0)	6(30.0)	-	-	-	-	-
	Dry After	NS	-	-	-	-	-	-	-	-	-	-	-
	Wet	16	1(6.3)	3(18.8)	-	4(25.0)	7(43.8)	1(6.3)	-	-	-	-	-
Total column		241	12	36	13	40	83	48			5	4	

Percentages in Parenthesis (   )

The same type of situation appears to exist at source and DN1 although the greater increases in S. faecalis var faecalis and S. faecium appear to be evidence of a slightly higher human fecal input during wet weather and possibly in the SED at DN1.

There is insufficient data on the flow from the SSO to show direct impact by bacterial species. It can be seen, however, that the SSO does carry loadings from mixed inputs. The higher representation of S. faecium, in the SSO in comparison to the river, may in part come from human fecal inputs. Conditions during wet weather indicate a dilution of the original loadings by storm run-off that would contain non-human and non-fecal material.

Bacterial Survival

The summer die-off rates as determined in-situ at source (Table 6, Fig. 11), indicate that there is an impact on the site that is having an abnormally high toxic effect on the two streptococci species tested. Both decreased more rapidly than E. coli during the first 24 hrs. The S. faecium appeared to be more resistant with its die-off rate decreasing while S. faecalis could not be recovered after 24 hrs. of exposure. S. faecalis has been found to decrease more rapidly than E. coli in other areas (34) but generally streptococci survive better than E. coli (42). This type of isolated effect is unlikely to affect the overall die-off rates as bacteria are transported downstream since they will actually be exposed to a continuously changing

Table [illegible]

Percent die-off of fecal indicator bacteria at Elhart Drive storm sewer site during summer weather conditions (Average water temperature $20 \pm 3^{o}C$)

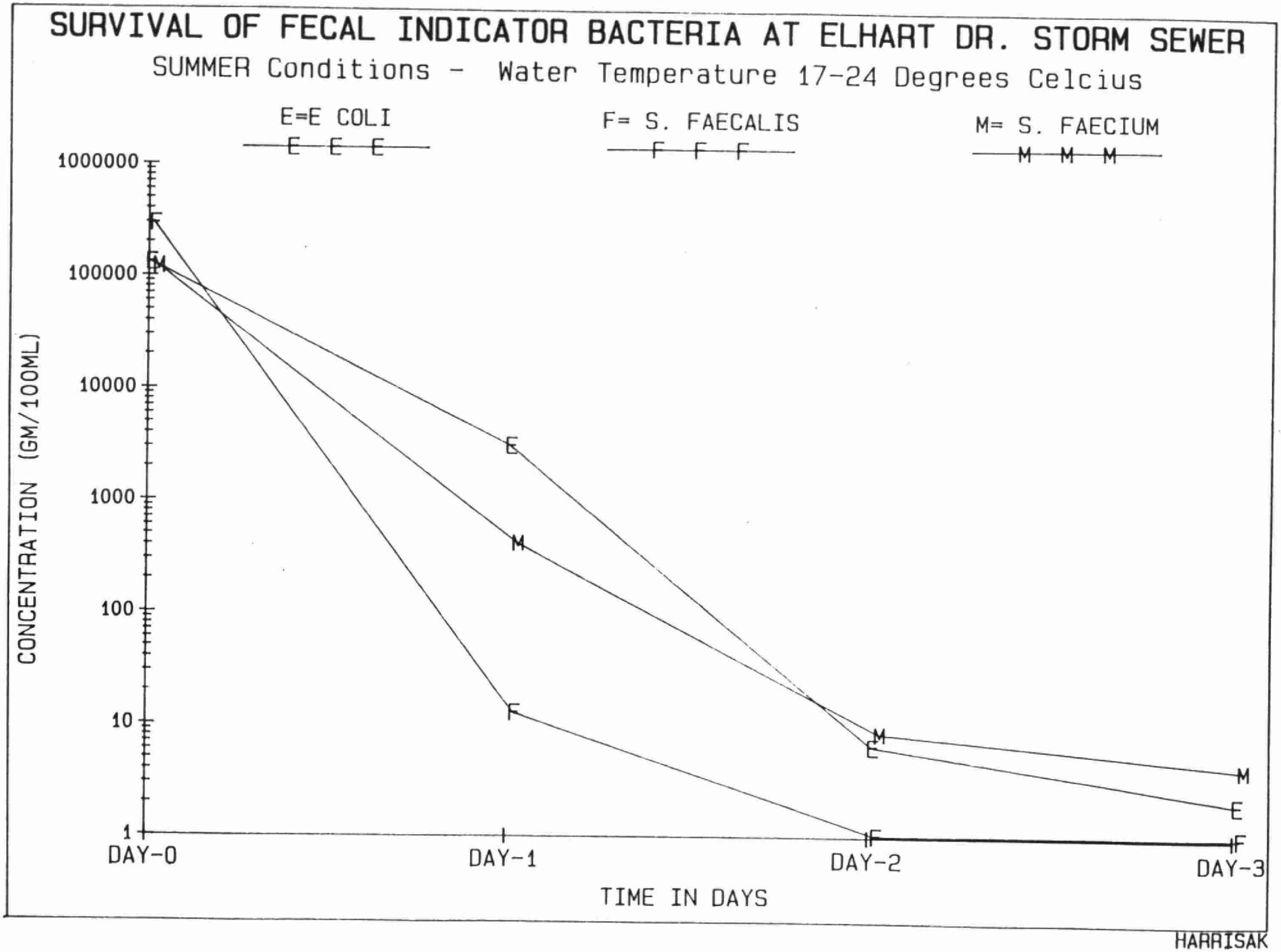
Bacterial Culture	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli (50 ml chamber)	1.3×10^5	3.1×10^3	6.3	2.0
Escherichia coli (100 ml chamber)	8.6×10^4	contaminated	-	-
Strep. faecalis (50 ml chamber)	2.9×10^5	12.4	1/ml	1/ml
Strep. faecalis (100 ml chamber)	2.9×10^5	contaminated	-	-
Strep. faecium (50 ml chamber)	1.2×10^5	4.1×10^2	8.1	4.1

Table 7:

Percent die-off of fecal indicator bacteria at Elhart Drive storm sewer site during winter weather conditions (Average water temperature $8.5 \pm 4^{o}C$)

Bacterial Culture (50 ml chamber)	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli	6.6×10^4	2.2×10^2	64.8	14.2
Strep. faecalis	1.1×10^5	6.8×10^4	3.3×10^4	2.4×10^4
Strep. faecium	3.4×10^4	2.5×10^4	1.1×10^4	3.1×10^3

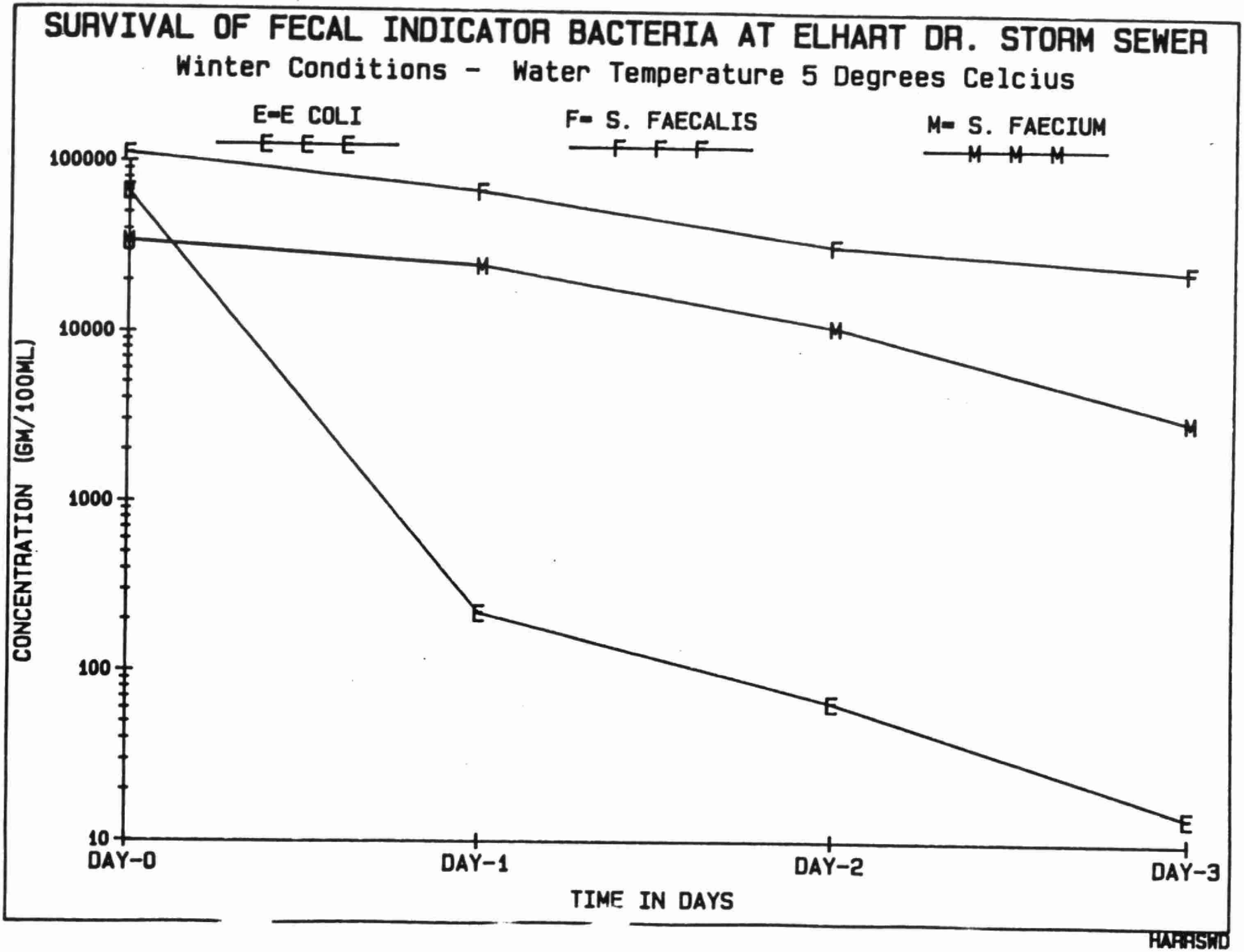
Figure 11:


SURVIVAL OF FECAL INDICATOR BACTERIA AT ELHART DR. STORM SEWER
SUMMER Conditions - Water Temperature 17-24 Degrees Celcius
E=E COLI
F= S. FAECALIS
M= S. FAECIUM
CONCENTRATION (GM/100ML)
1000000
100000
10000
1000
100
10
1
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISAK

environment. The possibility that the observations made were the result of an ongoing impact at this site or an anomaly could only be determined by additional testing.

The effect of decreased temperature on bacteria is to reduce their metabolism. In an environment where die-off is caused primarily by osmotic stress and insufficient nutrients, if all other factors remained the same the expected outcome would be a decrease in the die-off rate. However, since we are dealing with a natural dynamic system, conditions affecting the bacteria do change and observations made at the same location at two different times are in fact made under differing conditions. Thus the increased die-off rate of E. coli under colder water temperatures during the first 24 hrs. indicate that some other environmental factors other than temperature have also changed (Table 7, Fig. 12). The die-off rate does however, decrease considerably during the last 48 hrs. This may be due to changing environmental conditions and/or that the remaining bacteria are variants within the original population that are better able to survive. Both streptococci obviously survive much better during "winter conditions" at this site.

Figure 12:



SURVIVAL OF FECAL INDICATOR BACTERIA AT ELHART DR. STORM SEWER
Winter Conditions - Water Temperature 5 Degrees Celcius
E=E COLI
F= S. FAECALIS
M= S. FAECIUM
100000
10000
1000
100
10
CONCENTRATION (GM/100ML)
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRSWD

BLACK CREEK (Combined Sewer)

Sediment Resuspension

Sediment

The S.SED levels before and after MSR during dry weather (Fig. 13, Table 8) indicate that sedimentation is occurring at all sites with DN1 the area of greatest sediment deposition followed by source. Since only a very small flow was emanating from the CSO under dry conditions (insufficient to sample) the SED is probably from upstream of this location.

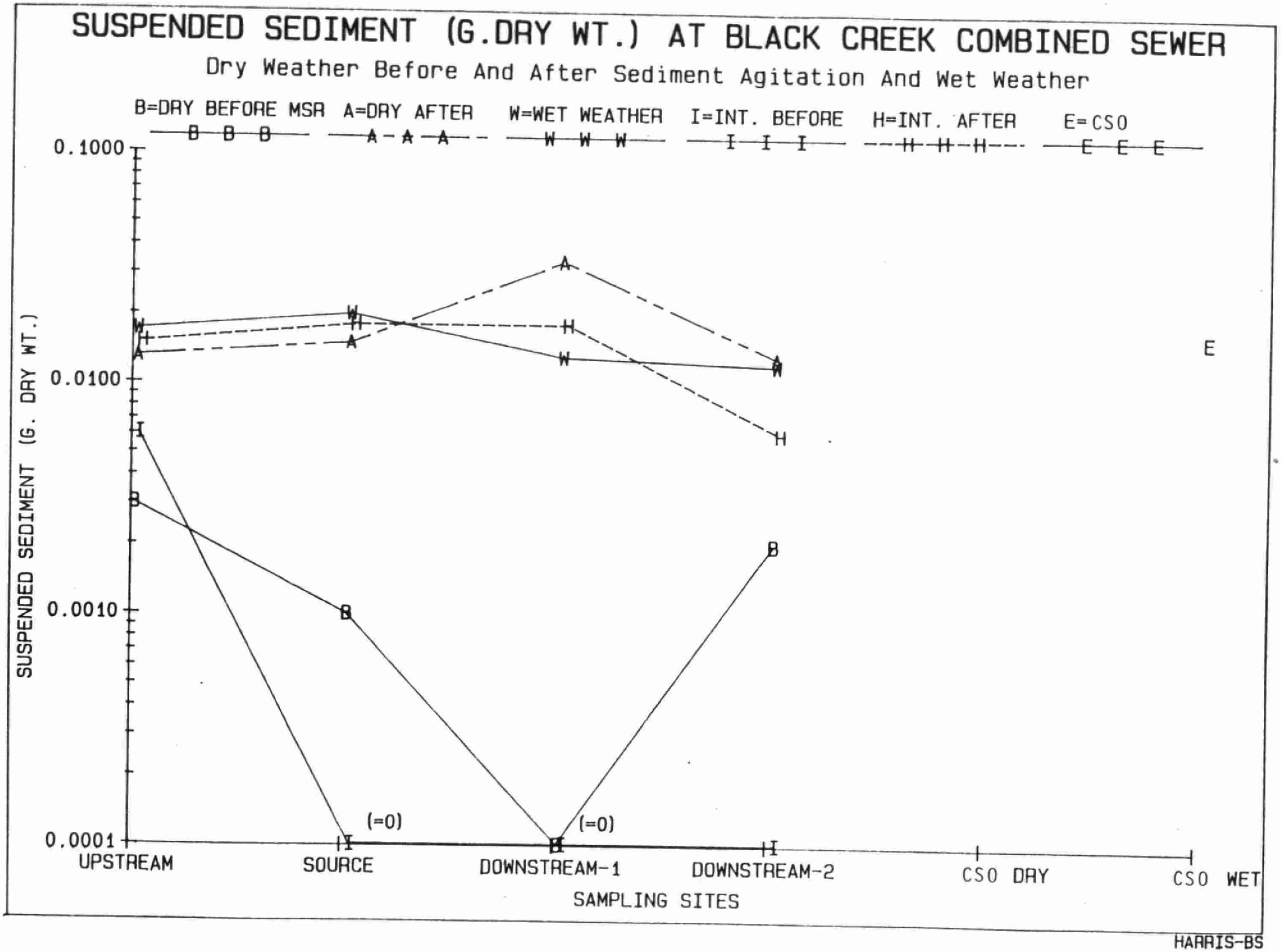
Wet weather once again dramatically increases S.SED in the water column. There is still an indication of some sedimentation occurring at DN1 under conditions existing at the time of sampling (i.e. drop in water column SED levels).

The change from wet to intermediate conditions appears to increase deposition through sites source to DN2. The decrease in flow after the end of a storm event, which can be quite rapid at this location could be the cause of the increased deposition.

Bacteria

The dry weather input from the combined sewer outfall (CSO), which was observed to be very small, has little impact on FIB levels in Black Creek (Figs. 14 to 18). The increases that were observed both before and after MSR tended to be at the downstream sites. This may have been due to the small input being missed at the source site while being somewhat more dispersed through the water column in the area of the downstream sites. In addition,

Figure 19.



SUSPENDED SEDIMENT (G.DRY WT.) AT BLACK CREEK COMBINED SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=CSO
SUSPENDED SEDIMENT (G. DRY WT.)
0.1000
0.0100
0.0010
0.0001
(=0)
(=0)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CSO DRY
CSO WET
SAMPLING SITES
HARRIS-BS

Table 8:

Geometric mean concentrations of Fecal Indicator Bacteria, E. coli to Fecal Coliform ratios, Fecal Coliform to Fecal Streptococci Ratios and Suspended Sediment Weights During Dry and Intermediate Weather (Before and After Sediment Agitation) and Wet Weather at Black Creek Combined Sewer Outfall No. 159.

Sampling site and weather cond.		Fecal coliforms	E. coli	Fecal Streptococci	Enterococci	P. aeruginosa	EC/FC Ratio	FC/FS Ratio	Suspended sediment (grams/100mls)
		(per 100 ml water sample)							
upstream dry	B	819	572	248	187	6.3	0.70	3.3	0.003
	A	1,368	666	415	431	8.3	0.49	3.3	0.013
Int.	B	257	194	122	84	16	0.75	2.1	0.006
	A	1,434	995	594	576	38	0.69	2.4	0.015
wet		18,091	10,320	10,427	11,885	260	0.57	1.7	0.017
source dry	B	959	566	210	171	6.0	0.59	4.6	0.001
	A	896	599	272	150	10.8	0.67	3.3	0.015
Int.	B	563	419	214	130	27	0.74	2.6	0.000
	A	852	621	341	288	44	0.73	2.5	0.018
wet		14,517	9,336	12,602	6,634	281	0.64	1.2	0.020
downstream I									
dry	B	1,262	1,023	402	305	9.2	0.81	3.1	0.000
	A	1,835	1,323	378	342	9.9	0.72	4.9	0.034
Int.	B	319	225	145	61	16	0.70	2.2	0.000
	A	997	812	827	380	45	0.81	1.2	0.018
wet		13,006	7,405	11,826	9,162	409	0.57	1.1	0.013
downstream II									
dry	B	938	668	264	176	10.5	0.71	3.6	0.002
	A	1,199	915	477	404	10.0	0.76	2.5	0.013
Int.	B	335	105	293	58	18	0.31	1.1	0.000
	A	642	549	164	205	60	0.85	3.9	0.006
wet		9,316	6,279	11,173	8,717	439	0.67	0.8	0.012
CSO	dry	-	-	-	-	-	-	-	-
	Int	-	-	-	-	-	-	-	-
	wet	1,500,000	1,100,000	70,000	60,000	1,810	0.73	21.4	0.016

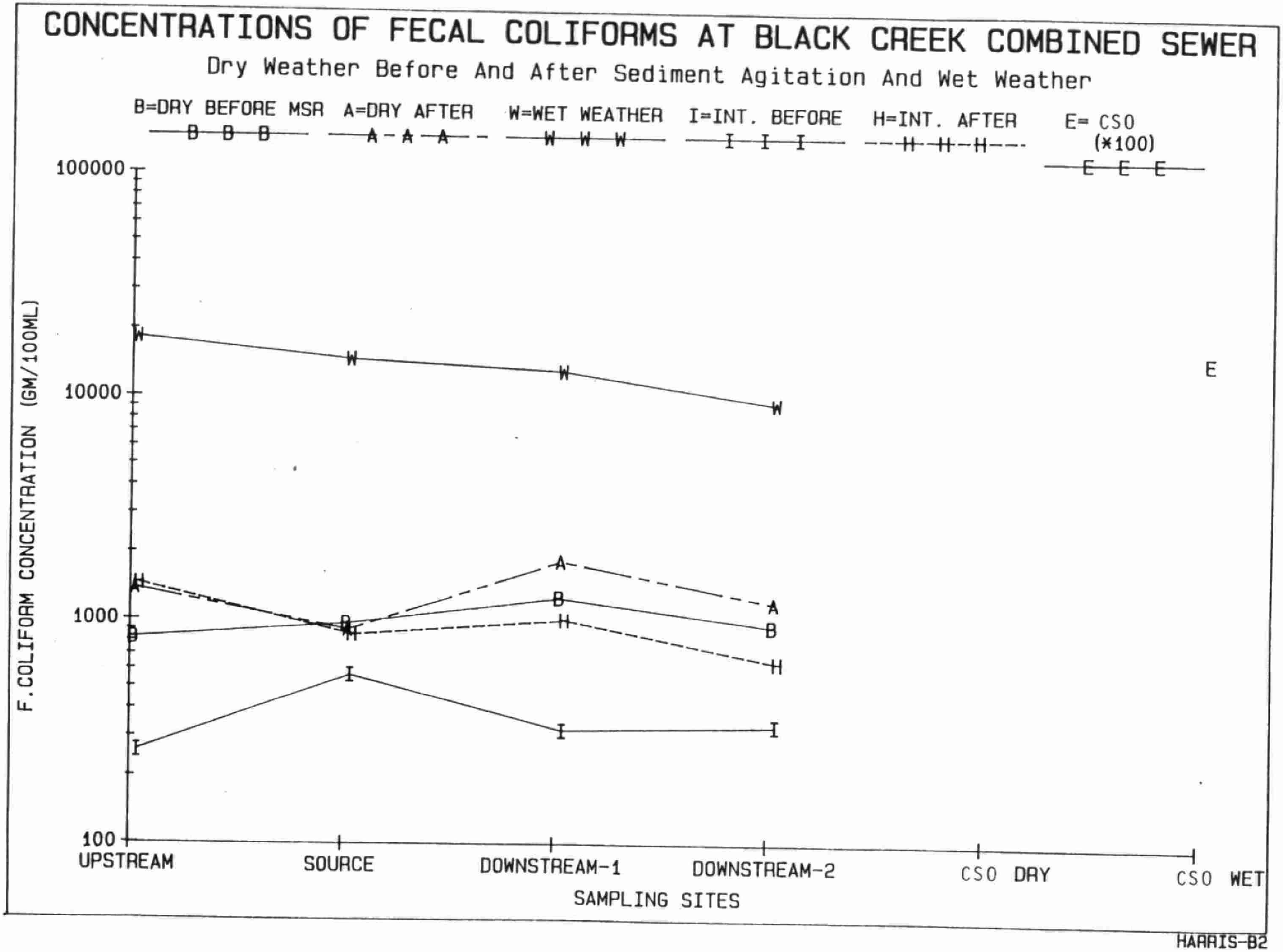

CONCENTRATIONS OF FECAL COLIFORMS AT BLACK CREEK COMBINED SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E= CSO (*100)
F.COLIFORM CONCENTRATION (GM/100ML)
100000
10000
1000
100
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CSO DRY
CSO WET
SAMPLING SITES
HARRIS-B2

Figure 15:

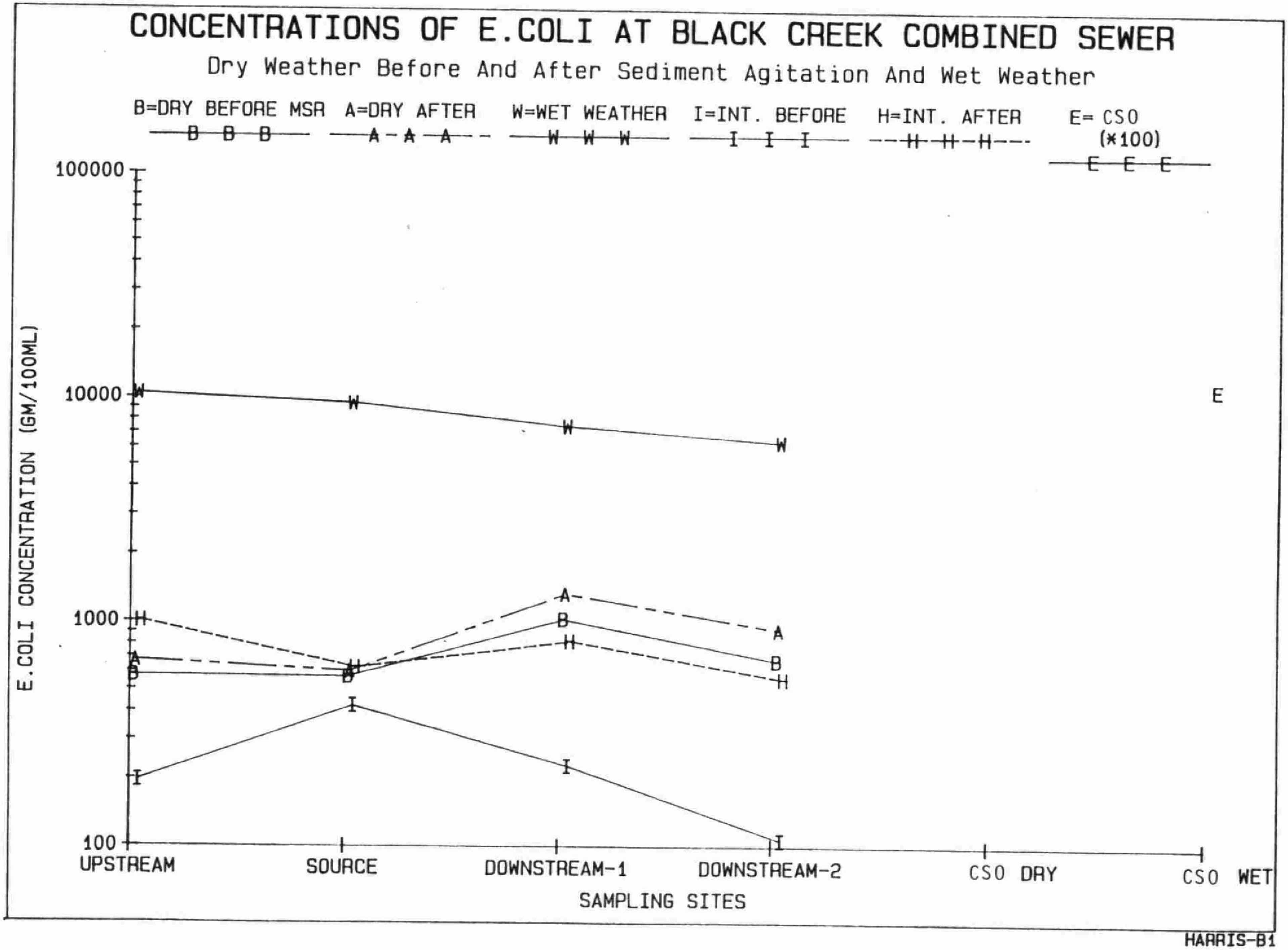
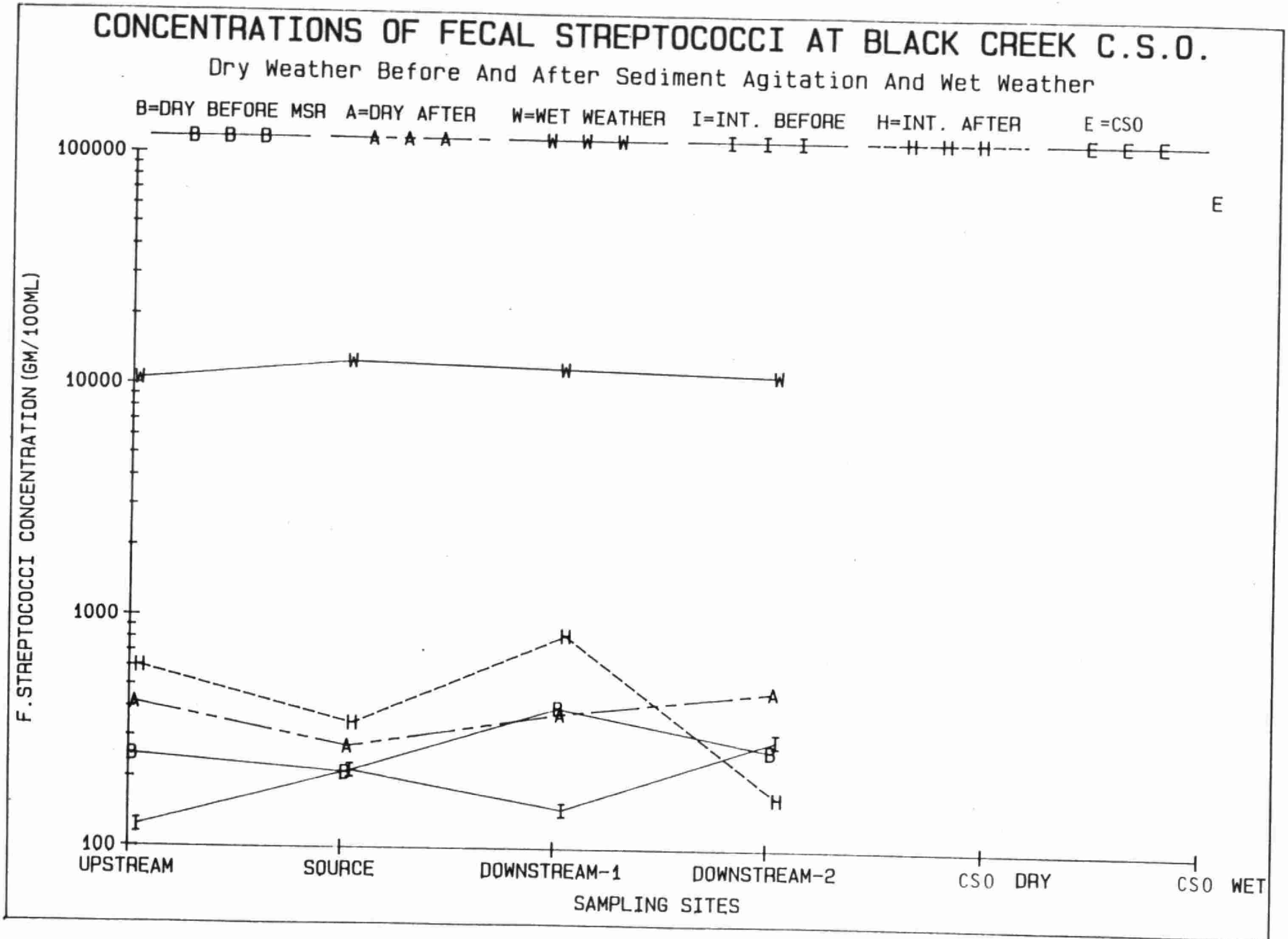
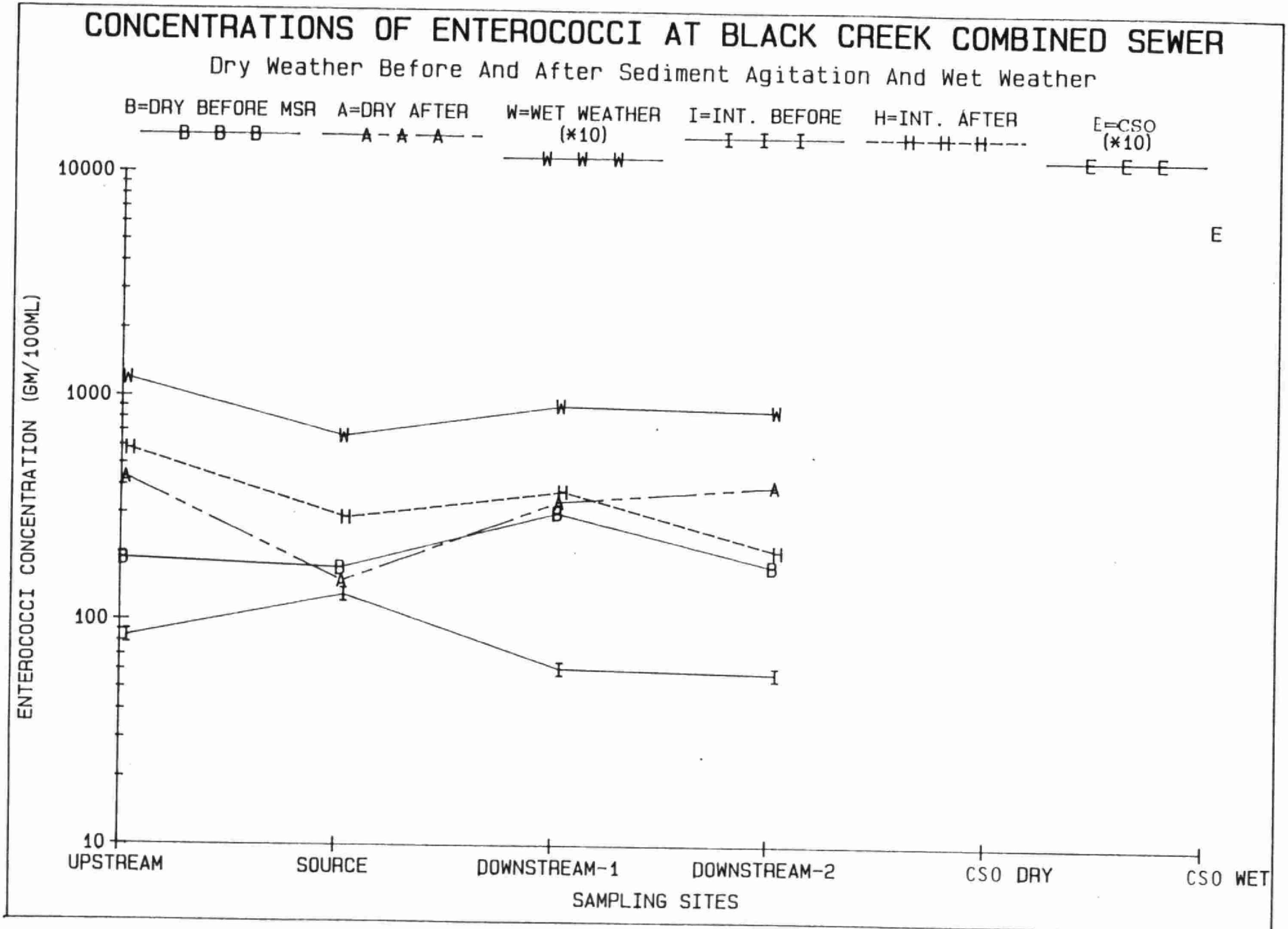

CONCENTRATIONS OF E.COLI AT BLACK CREEK COMBINED SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E= CSO (*100)
100000
10000
1000
100
E.COLI CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CSO DRY
CSO WET
SAMPLING SITES
HARRIS-B1

Figure 16:

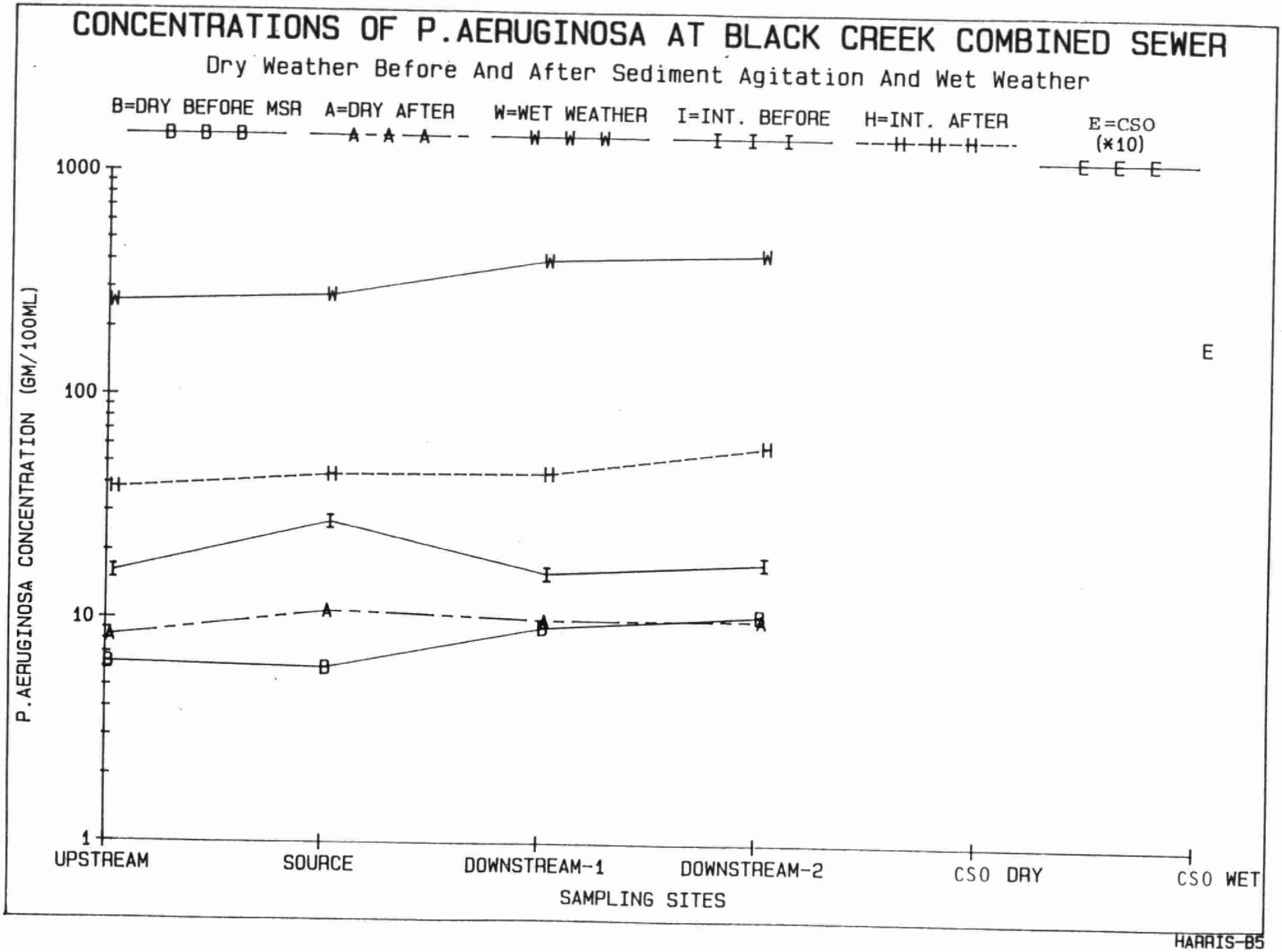

CONCENTRATIONS OF FECAL STREPTOCOCCI AT BLACK CREEK C.S.O.
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E =CSO
100000
10000
1000
100
F.STREPTOCOCCI CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CSO DRY
CSO WET
SAMPLING SITES
HARRIS-B3

[redacted]Fi[redacted]e 1[redacted]



HARRIS-B4

Figure 18.



CONCENTRATIONS OF P.AERUGINOSA AT BLACK CREEK COMBINED SEWER
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=CSO (*10)
P.AERUGINOSA CONCENTRATION (GM/100ML)
1000
100
10
1
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CSO DRY
CSO WET
SAMPLING SITES
HARRIS-B5

the sediments at the source site are sandy and thus would adsorb bacteria poorly (4). This would lead to lower accumulation per unit weight and easier desorption and thus transference downstream.

The FIB densities in the CSO outflow were very high during wet weather conditions while the sewer was active. The instream loading through the area was so great, however, that the increased loadings from the CSO had little impact. The only parameters that may be responding to an input are FS (Fig. 16) and PSA (Fig. 18). It is difficult to understand why these two parameters would be affected by the CSO input while FC (Fig. 14) and EC (Fig. 15) are not since the concentration of the latter bacteria in the CSO is considerably greater relative to instream levels than that of FS or PSA. It may be that both FS and PSA tend to survive better in the sediments and that their water column densities are greatly increased by sediment resuspension during storms.

The continued impact from the CSO during intermediate conditions, while river flow and FIB concentrations are reduced, is sufficient to demonstrate an impact on Black Creek at source. The decrease in FIB densities in the water column below those occurring during dry weather indicate that Black Creek undergoes a scouring or flushing effect during storm events.

MSR results indicate the possibility of a small impact by the CSO at DN1, however, the generally higher effect on streptococci and lack of response in PSA indicate that a majority of the

sediment accumulating is from upstream containing less recent fecal or non-fecal inputs.

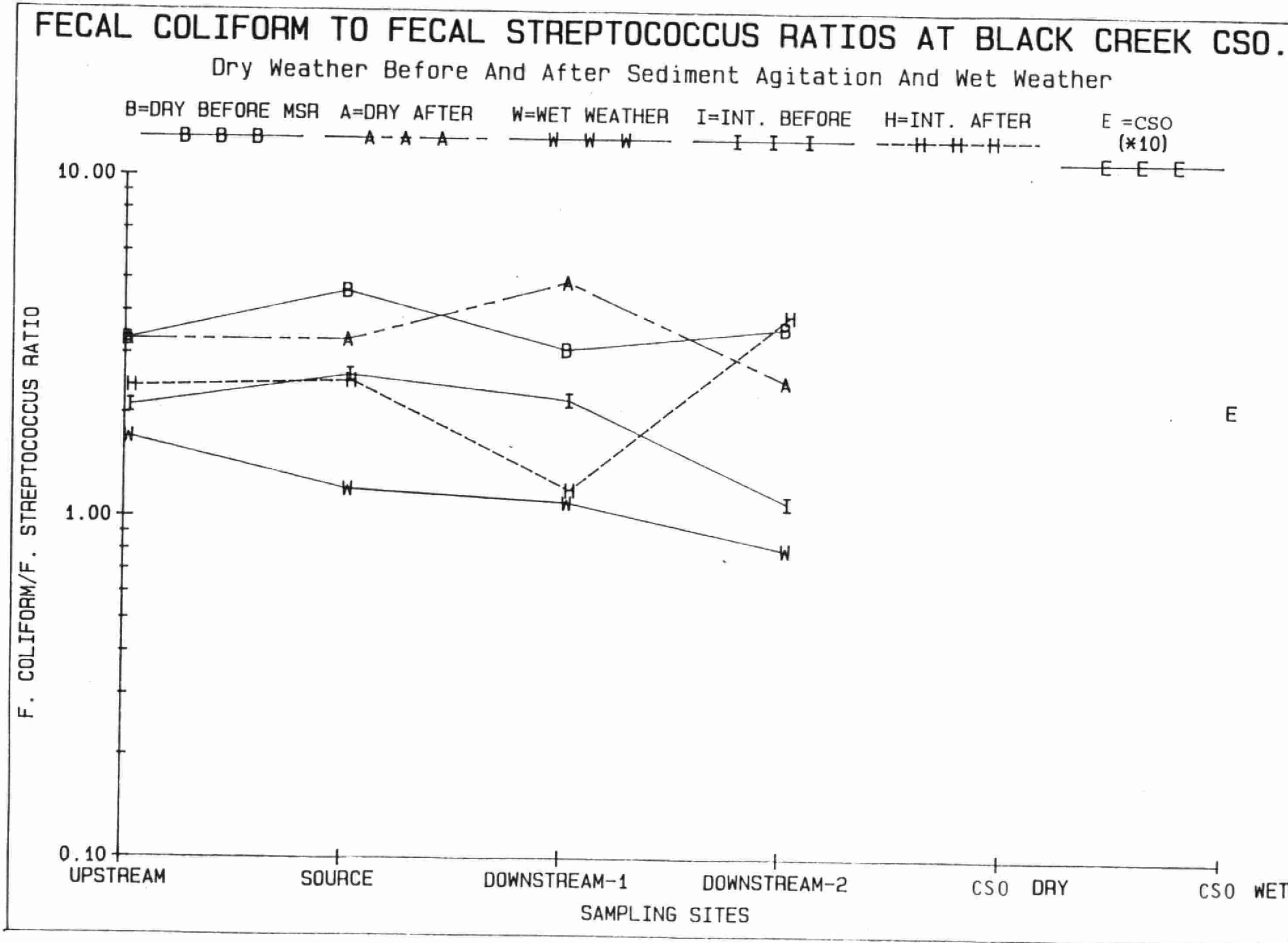
FC/FS

The FC/FS ratio in the water column appears to react somewhat to the CSO input at source during dry weather (Fig. 19). It is interesting to note that although FC and FS individually showed a greater response to the CSO at DN1, the FC/FS is increasing at source and not at DN1.

The input of large amounts of non-fecal matter and old fecal accumulations has the net effect of decreasing FC/FS ratios throughout this location. No effect from the CSO was noted even though the ratio was considerably higher than in-stream. The FC/FS ratio of 21.4 in the CSO effluent indicates the possibility of human fecal input, which is to be expected in a combined sewer.

During intermediate conditions the FC/FS ratios are still depressed below dry weather levels but they do appear to react to the CSO input. MSR results suggest that under intermediate conditions impact on the SED has shifted to DN2 although once again actual densities are higher at a different site (i.e. DN1). The reasons for the FC/FS ratio and measured densities reacting differently undoubtedly relates to the combination of original sources of bacteria impacting on a given site and their input location relative to the site being studied. It is beyond the scope of this study to determine what permutations and

Fi[redacted]e [redacted]



HARRIS-BR

combinations would lead to the observations made at this location. It becomes apparent, however, that in designing a survey, a reliance on too few stations and/or parameters will result in the inability to locate areas of impact.

Post-Rainfall Bacterial (EC/FC) Quality

The dramatic drop in FC and EC densities directly after wet weather is followed by considerable day to day variability (Table 9). The densities on day 3 usually exceed those on day 1, but pollution loadings remain well below those observed during storm events.

The EC/FC levels indicate somewhat less recent impact during wet weather (.5-.7) than the period immediately following (.7-1.0). This is the normal response in a system such as this because of the variety of inputs (type, age, distance) impacting during a storm.

At UP, before MSR, the EC/FC post-rainfall levels (Table 9) show no obvious trend over the period monitored and the mean values (Table 8) also show almost no difference between intermediate and dry conditions. The EC/FC values following MSP indicate that during dry weather impacts are probably from more distant sources and thus, after the initial deposition of SED following a storm, the ratios decrease. Again it should be noted that this is not a direct contradiction of the FC/FS ratios which show a reverse trend. This type of difference may mean that during dry weather there is a somewhat larger proportion of the

Table 9:

Escherichia Coli to Fecal Coliform Ratios during Post-Rainfall Period at Black Creek Combined Sewer

Site	Number of Days Following Rainfall				
	0	1	2	3	4
UB	10320/18091 (0.57)	194/257 (0.75)	454/559 (0.81)	668/1057 (0.63)	300/390 (0.77)
UA		995/1434 (0.69)	363/738 (0.49)	997/2066 (0.48)	470/1140 (0.41)
SB	12517/20030 (0.62)	419/563 (0.74)	327/553 (0.59)	816/1384 (0.60)	460/516 (0.89)
SA		621/852 (0.73)	421/559 (0.75)	758/1227 (0.62)	432/488 (0.88)
DN1B	15572/23835 (0.65)	1025/1025 (1.0)	327/478 (0.68)	2185/2411 (0.91)	364/448 (0.81)
DN1A		812/997 (0.81)	536/749 (0.72)	2417/3335 (0.72)	620/830 (0.75)
DN2B	15079/22357 (0.67)	1073/1368 (0.78)	386/520 (0.74)	962/1389 (0.69)	410/460 (0.89)
DN2A		1517/1865 (0.81)	392/587 (0.67)	1067/1929 (0.55)	170/410 (0.41)
CSO	100000/500000 (0.2)	--	--	--	--

E.coli / F. coliforms (Ratio) *approximate value

pollution loading that are originally fecal in origin, but they are somewhat "less fresh" than during the intermediate conditions.

The changes in EC/FC at source, before MSR (Table 9), are somewhat different than at Up in that there appears to be a dilution effect on day 2 as well as day 3. Possibly there is an impact from resuspended sediment upstream. The mean results indicate that although the EC/FC ratio on day 4 indicates more recent inputs, the average intermediate impact tends to include fresher fecal material than dry. The effect of MSR is minimal with the only change being an increase in EC/FC on day 2. There is no obvious trend and the mean results show very little difference between intermediate and dry conditions.

The EC/FC post-rainfall values at DN1 and DN2, before MSR, suggest that there is a more recent impact during dry weather once the creek has recovered from the storm event. This change could be in part due to the small input from the effluent. The mean values show the same effect. MSR data following rainfall indicates a decreasing effect from recent inputs on the sediment and this is confirmed by the mean EC/FC data. This would indicate that there is little dry weather build up of fecal indicator bacteria from "recent" inputs to the sediments during dry weather.

Natural Environmental Phenomenon and Bacterial Concentrations

The increase in flow, S.SED and bacterial concentrations as a result of a wet weather event can be observed during the second, third and fourth surveys (Figs. 20, 21, 10A, and 10B). Exact relationships cannot be determined, however, because of the lack of data. The third survey (July 2-4) is the only one in which all parameters peaked at the same time. During the second survey it appears as if the bacteria reached maximum levels first while during the fourth survey high levels of bacteria and sediment had been "flushed out" before peak flow was reached.

The first survey data indicates that flow and bacterial level appear to be stabilizing, while S.SED is still decreasing probably as a result of a flushing effect that has reduced inputs along with decreased resuspension.

The final survey (July 29-31) occurred during a period of relative stability and thus it is harder to explain the changes in SED and bacteria. The decrease in SED may be due to increasing sedimentation while the increase in bacterial levels may be due to point source inputs such as the CSO.

The regression analysis of sediment from each site (Table 10) demonstrated no trends. The strong correlation between all sites particularly with source, suggest that the main impact on SED is from upstream with some additional impact from the effluent.

The most interesting outcome of the bacteria/sediment regression analysis is the significant negative correlations

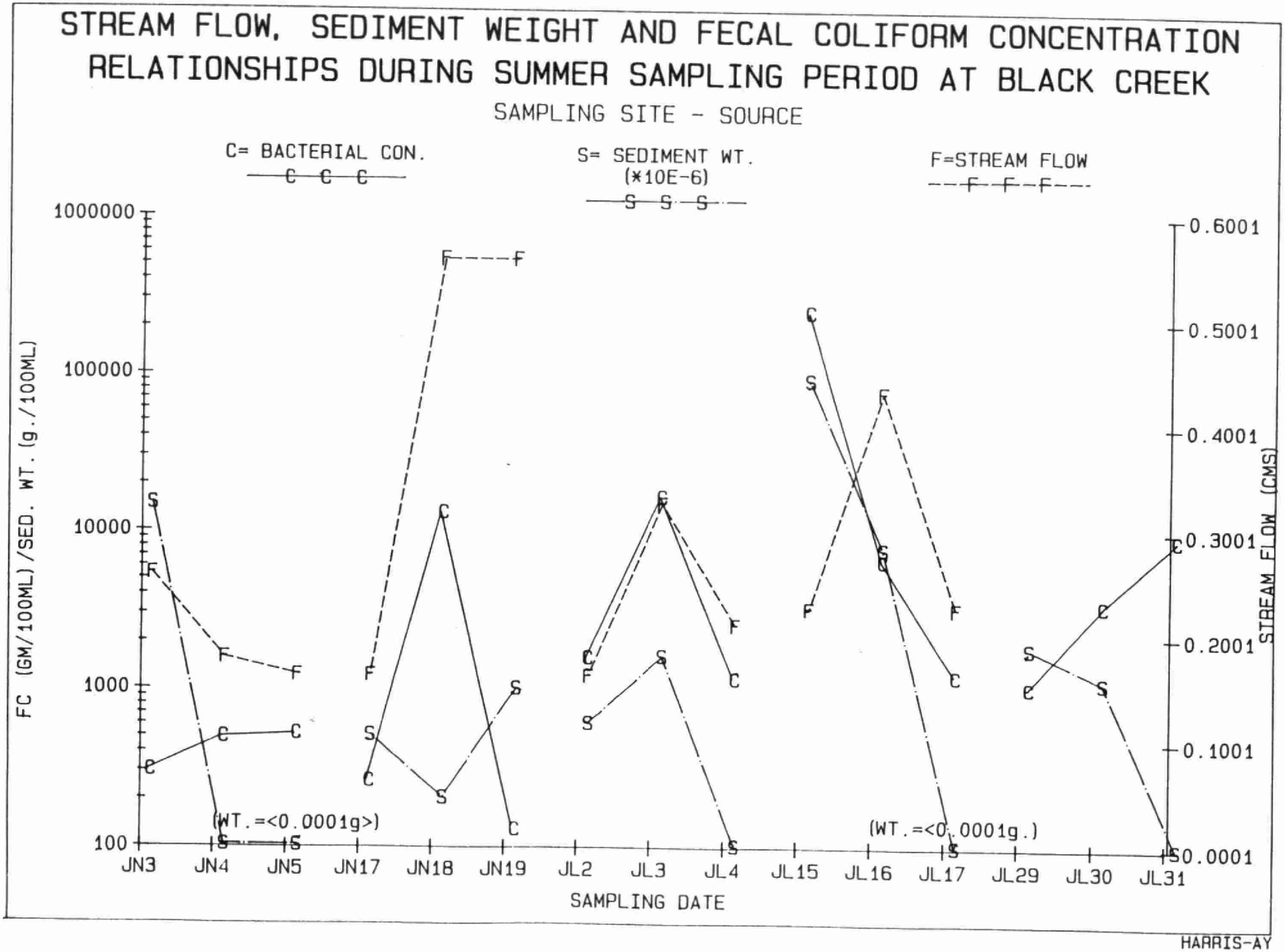

STREAM FLOW, SEDIMENT WEIGHT AND FECAL COLIFORM CONCENTRATION RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT BLACK CREEK
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT. (*10E-6)
F=STREAM FLOW
FC (GM/100ML)/SED. WT. (g./100ML)
STREAM FLOW (CMS)
1000000
100000
10000
1000
100
0.6001
0.5001
0.4001
0.3001
0.2001
0.1001
0.0001
(WT.=<0.0001g>)
(WT.=<0.0001g.)
JN3
JN4
JN5
JN17
JN18
JN19
JL2
JL3
JL4
JL15
JL16
JL17
JL29
JL30
JL31
SAMPLING DATE
HARRIS-AY

Figure 21:

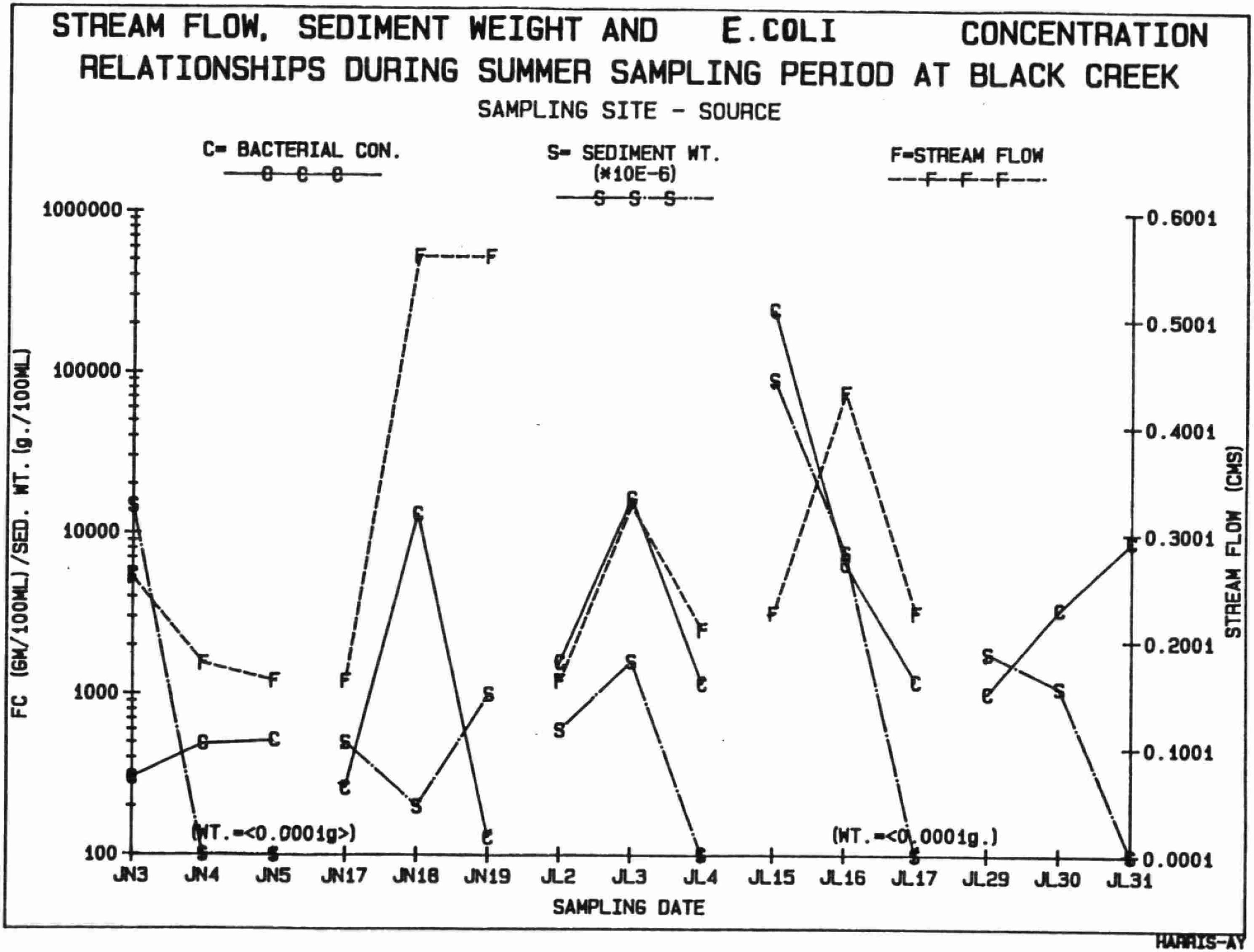

STREAM FLOW, SEDIMENT WEIGHT AND E.COLI CONCENTRATION
RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT BLACK CREEK
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT. (*10E-6)
F=STREAM FLOW
FC (GM/100ML)/SED. WT. (g./100ML)
1000000
100000
10000
1000
100
STREAM FLOW (CMS)
0.6001
0.5001
0.4001
0.3001
0.2001
0.1001
0.0001
(WT.=<0.0001g>)
(WT.=<0.0001g.)
JN3
JN4
JN5
JN17
JN18
JN19
JL2
JL3
JL4
JL15
JL16
JL17
JL29
JL30
JL31
SAMPLING DATE
HARRIS-AY

Table 10:

Correlation Coefficients of Suspended Sediment Weights (Before Sediment Agitation) with Fecal Coliform, Escherichia coli Counts and Flow Rate at Black Creek Combined Sewer

Sediment Weight	Sediment Weight			
	Upstream	Source	Downstream I	Downstream II
Upstream	+ 1.00	+ 0.96	+ 0.95	+ 0.96
Source		+ 1.00	+ 1.00	+ 1.00
Downstream I			+ 1.00	+ 0.99
Downstream II				+ 1.00
Fecal coliforms				
Upstream	+ 0.47	+ 0.48	+ 0.51	+ 0.48
Source	+ 0.46	+ 0.53	+ 0.58	+ 0.52
Downstream I	- 0.67	- 0.67	- 0.63	- 0.67
Downstream II	+ 0.50	+ 0.54	+ 0.58	+ 0.53
E. coli				
Upstream	+ 0.43	+ 0.44	+ 0.47	+ 0.43
Source	+ 0.45	+ 0.53	+ 0.58	+ 0.51
Downstream I	- 0.66	- 0.66	- 0.62	- 0.66
Downstream II	+ 0.56	+ 0.62	+ 0.67	+ 0.60
Flow rate	- 0.08	- 0.05	- 0.01	- 0.06

between EC and FC at DN1 with SED from all sites. This would indicate an impact on EC and FC levels at DN1 which is not affecting UP or source and is gone again at DN2. The positive correlation between E. coli at DN2 and SED at source, DN1 and DN2 indicates that fecal pollution at DN2 is dominated by an impact at source that is effecting SED levels. It may be the effluent, CSO or resuspension plus upstream loadings to a lesser extent.

The regression analyses of FC and EC data (Table 11) indicates that although there may be some impact occurring at source the major impact, except at DN1, is from upstream. The correlation coefficients for analyses at DN1 show no relation to the other sites suggesting a unique source of impact. The most likely source is the small but highly contaminated impact from the CSO.

Flow shows no significant relationship to the other parameters and as it is only one of a number of the factors governing SED and bacterial concentrations.

Streptococcus Populations

The streptococcus results are indicative of mixed source inputs during dry weather (Table 12). The relative representation of S. faecium var faecium to S. faecalis var liquefaciens and S. durans with the presence of low levels of S. faecalis var faecalis indicate some of the input is probably from human sources.

Table 11:

Correlation Coefficients of Fecal Coliform, Escherichia coli Counts and Flow Rate at Black Creek Combined Sewer

E. coli	Fecal Coliforms			
	Upstream	Source	Downstream I	Downstream II
Upstream	+0.99	+ 0.91	+ 0.30	+ 0.97
Source	+0.91	+ 0.99	+ 0.22	+ 0.96
Downstream I	+0.29	+ 0.24	+ 1.00	+ 0.25
Downstream II	+0.97	+ 0.98	- 0.02	+ 0.99
Fecal coliforms				
Upstream	+ 1.00	+ 0.92	+ 0.28	+ 0.98
Source		+ 1.00	+ 0.23	+ 0.97
Downstream I			+ 1.00	+ 0.23
Downstream II				+ 1.00
Flow rate	+ 0.41	+ 0.56	+ 0.50	+ 0.46
E. coli	E. coli			
Upstream	+1.00	+ 0.90	+ 0.32	+ 0.97
Source		+ 1.00	+ 0.23	+ 0.99
Downstream I			+ 1.00	- 0.02
Downstream II				+ 1.00
Flow rate	+ 0.47	+ 0.53	+ 0.51	+ 0.57

Table 12:

Fecal Streptococcus Populations at Black Creek Combined Sewer Under Wet and Dry Weather Conditions

Site and cond.		Total Isolates	S.faecalis faecalis	S.faecalis liquefaciens	S.faecalis zymogenes	S.faecium	S. faecium casseliflavus	S.durans	S.bovis	S.avium	Fecal Strep.	Non-fecal streptococci	Aerococcus
UPSTRM	Dry Before	28	2(25.0)	7(7.1)	-	12(42.9)	2(7.1)	4(14.3)	-	-	1(3.6)	-	-
	Dry After	21	1(4.8)	5(23.8)	-	9(42.9)	4(19.0)	2(9.5)	-	-	-	-	-
	Wet	42	1(2.4)	15(35.7)	-	13(31.0)	4(9.5)	8(19.0)	-	-	-	1(2.4)	-
SOURCE	Dry Before	28	3(10.7)	3(10.7)	-	10(35.7)	4(14.3)	8(28.6)	-	-	-	-	-
	Dry After	48	1(2.1)	7(14.6)	2(4.2)	19(39.6)	9(18.8)	2(4.2)	-	-	7(14.6)	1(2.1)	-
	Wet	40	8(20.0)	13(32.5)	1(2.5)	5(12.5)	1(2.5)	10(25.0)	-	-	1(2.5)	1(2.5)	-
DOWNSTRM	Dry Before	27	2(14.8)	-	10(37.0)	4(14.8)	7(25.9)	-	-	-	-	-	-
	Dry After	23	1(4.3)	4(17.4)	-	9(39.1)	4(17.4)	3(13.0)	-	-	1(4.3)	1(4.3)	-
	Wet	41	7(17.1)	9(22.0)	-	8(19.5)	6(14.6)	10(24.4)	-	-	1(2.4)	-	-
CSO	Dry Before	NS	-	-	-	-	-	-	-	-	-	-	-
	Dry After	NS	-	-	-	-	-	-	-	-	-	-	-
	Wet	19	5(26.3)	3(15.8)	1(5.3)	-	-	10(52.6)					
Total column		317	31	70	4	95	38	63			11	4	

Percentages in Parenthesis (   )

The use of MSR had no dramatic effect on the streptococci species distribution. The small shifts occurring suggest that accumulating SED had somewhat more impact from animal/bird sources than the overlying water at the time of sampling.

Although one would expect increased loadings from human fecal sources at this location during wet weather, and they certainly appear to be present, their effect on bacterial populations appears to be masked by the large non-human/non-fecal loadings that also occur. Even in the CSO there were no S. faecium var faecium recovered. However, neither were S. faecium var casseliflavus, which could be the result of the limited number of isolates obtained.

The increase in S. faecalis var faecalis at source and DN1 may be indicative of the CSO impacting on the creek.

Bacterial Survival

Both S. faecalis and E. coli showed the ability to survive for extended periods of time during the summer (Fig. 22, Table 13). E. coli decreased somewhat more quickly overall, but at a much slower rate than observed at other locations. The factors buffering the E. coli from the effects of environmental stress may include the high nutrient levels in Black Creek.

Under winter conditions S. faecalis (Fig. 23, Table 14) continues to show good survival as does S. faecium. S. bovis, which has been shown to survive poorly in the environment (43), exhibited a very rapid decrease in levels.

Figure 22.

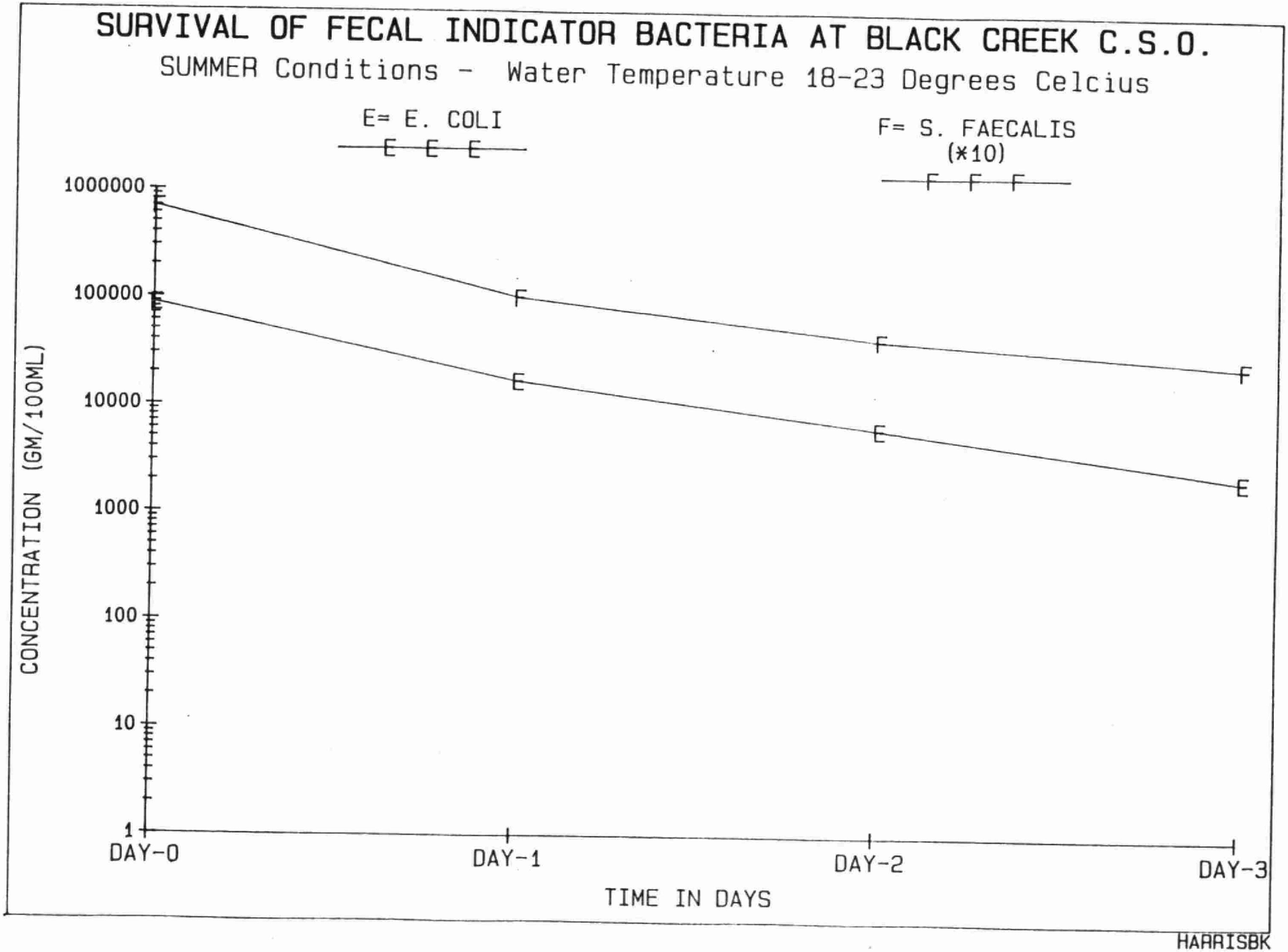

SURVIVAL OF FECAL INDICATOR BACTERIA AT BLACK CREEK C.S.O.
SUMMER Conditions - Water Temperature 18-23 Degrees Celcius
E= E. COLI
F= S. FAECALIS
(*10)
1000000
100000
10000
1000
100
10
1
CONCENTRATION (GM/100ML)
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISBK

Table 13:

Percent die-off of fecal indicator bacteria at Black Creek combined sewer site during summer weather conditions (Average water temperature 20 $\pm$ 3°C)

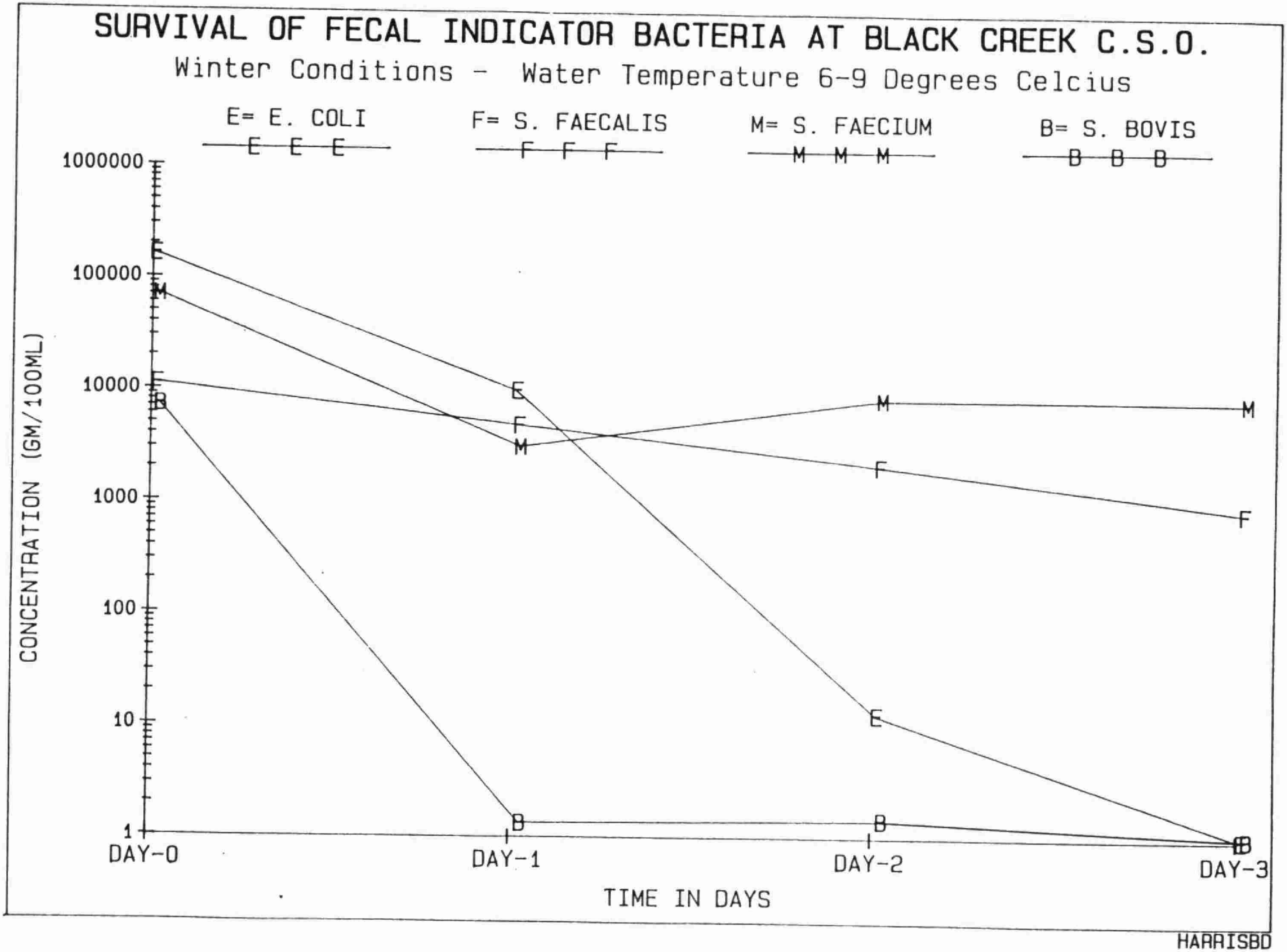
Bacterial Culture	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli (50 ml chamber)	8.6×10^4	1.7×10^4	6.2×10^3	2.2×10^3
Escherichia coli (100 ml chamber)	3.6×10^4	5.8×10^3	contaminated	contaminated
Strep. faecalis (50 ml chamber)	6.8×10^6	1.02×10^6	4.2×10^5	2.5×10^5
Strep. faecalis (100 ml chamber)	2.9×10^5	44	5.5	contaminated

Table 14:

Percent die-off of fecal indicator bacteria at Black Creek combined sewer site during winter weather conditions (Average water temperature 8.5 $\pm$ 4°C)

Bacterial Culture (50 ml chamber)	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli	1.6×10^5	9.9×10^3	12.4	<1
Strep. faecium	7.0×10^3	3.1×10^3	8.4×10^3	8.2×10^3
Strep. faecalis	1.1×10^4	4.8×10^3	2.1×10^3	8.4×10^2
Strep. bovis	7.1×10^3	1.3	1.4	1.0

Fi[redacted]e 2[redacted]



The sharp increase in the die-off rate of E. coli (Fig. 23, Table 14) is not likely due to the decreased temperatures since these tend to have a stabilizing effect. Other factors such as decreased levels of nutrients and increased levels of toxic materials are more probably the cause.

Emery Creek (Industrial Inputs)

Sediment Resuspension

Sediment

The observed levels of S.SED (Fig. 24, Table 15) in the water column during dry weather, prior to MSR, suggests that sedimentation may be occurring at source and DN1. Based on the relative increase in S.SED following MSR, however, the greatest amount of deposition is occurring at UP and DN1. SED deposition in the area of source and DN1 could be due in part to the inflow of Emery Creek which could also be having some dilution effect since S.SED levels are lower than those at UP. Deposited SED from source to DN2 probably originates from both upstream and Emery Creek with the largest loadings coming from upstream.

Under wet weather conditions S.SED was greatly increased by higher flows and inputs upstream, but the inflow of Emery Creek still appears to be having a diluting effect at source. The Creek undoubtedly has a minimal effect on the Humber River as a whole, but this site was located in the Creek's plume. The somewhat higher levels at DN2 could be from SED resuspension.

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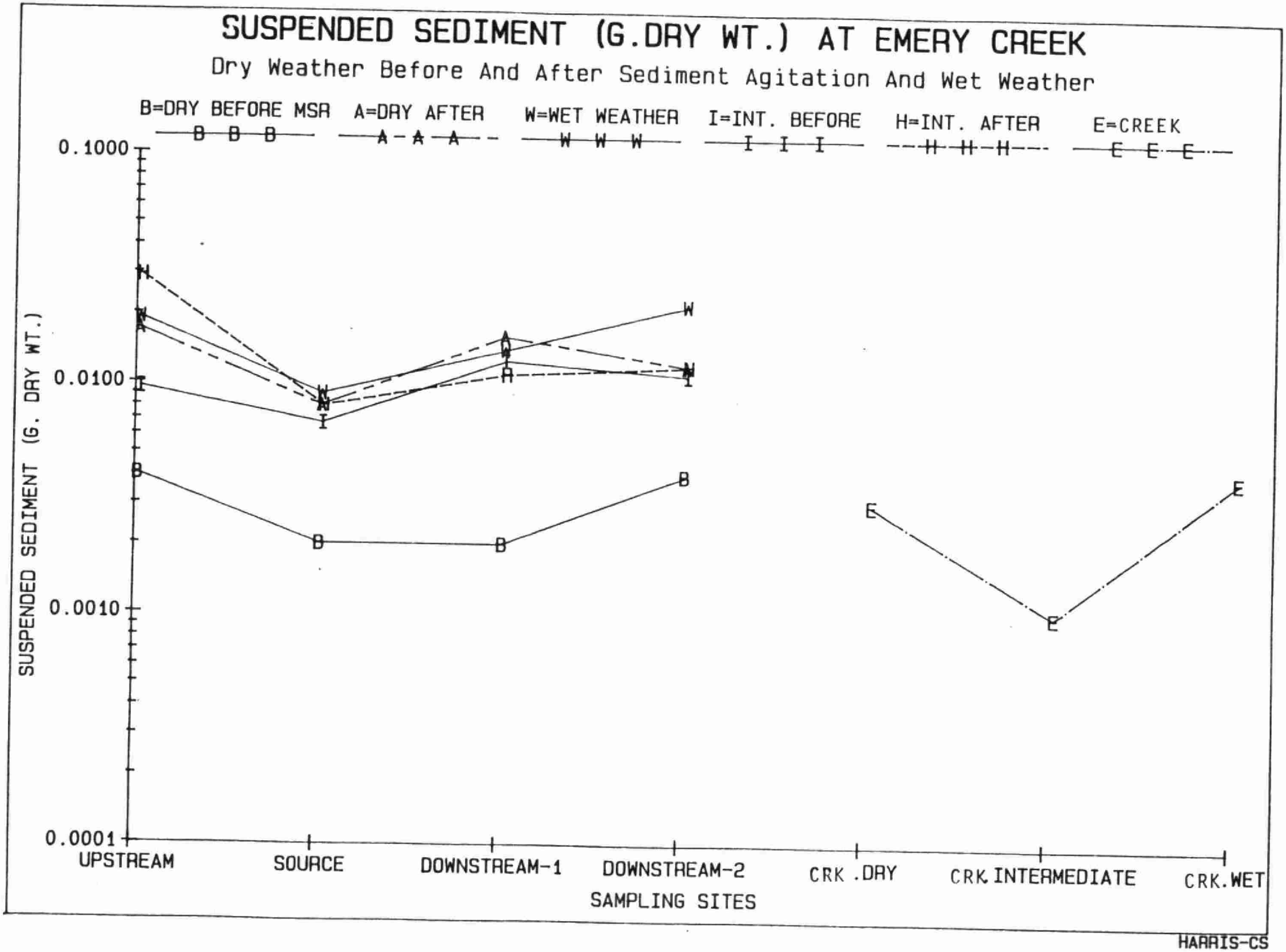


Table 15:

Geometric mean concentrations of Fecal Indicator Bacteria, E. coli to Fecal Coliform ratios, Fecal Coliform to Fecal Streptococci Ratios and Suspended Sediment Weights During Dry and Intermediate Weather (Before and After Sediment Agitation) and Wet Weather at Emery Creek

Sampling site and weather cond.		Fecal coliforms	E. coli	Fecal Streptococci	Enterococci	P. aeruginosa	EC/FC Ratio	FC/FS Ratio	Suspended sediment (grams/100mls)
		(per 100 ml water sample)							
upstream	B	385	321	118	65	3.9	0.80	3.3	0.004
dry	A	621	473	187	102	5.8	0.76	3.3	0.017
Int.	B	1,020	999	398	171	28	0.98	2.6	0.009
	A	819	534	487	403	37	0.65	1.7	0.029
wet		1,507	1,043	402	58	0.69	2.0	0.019	
source	B	1,368	613	232	138	82	0.45	5.9	0.002
dry	A	2,168	915	524	285	189	0.42	2.4	0.008
Int.	B	1,706	1,300	885	307	33	0.76	1.9	0.006
	A	3,612	2,236	2,670	440	20	0.62	1.4	0.008
wet		6,063	3,227	1,083	1,025	583	0.53	5.6	0.009
downstream I									
dry	B	517	348	119	76	11.7	0.67	4.3	0.002
	A	721	475	178	112	8.6	0.66	4.1	0.016
Int.	B	1,025	690	376	308	4.1	0.67	2.7	0.012
	A	845	585	356	371	23	0.69	2.4	0.011
wet		1,404	1,097	777	494	144	0.78	1.8	0.014
downstream II									
dry	B	657	497	108	76	19	0.76	6.1	0.004
	A	542	418	163	85	15	0.77	3.3	0.012
Int.	B	654	537	391	281	23	0.82	1.7	0.010
	A	800	793	363	229	19	0.99	2.2	0.012
wet		2,256	1,678	798	489	149	0.74	2.8	0.022
Creek	dry	2,211	848	403	217	176	0.38	5.5	0.003
	Int	2,728	1,432	1,475	496	180	0.52	1.8	0.001
	wet	9,649	4,981	2,591	1,196	727	0.52	3.7	0.004

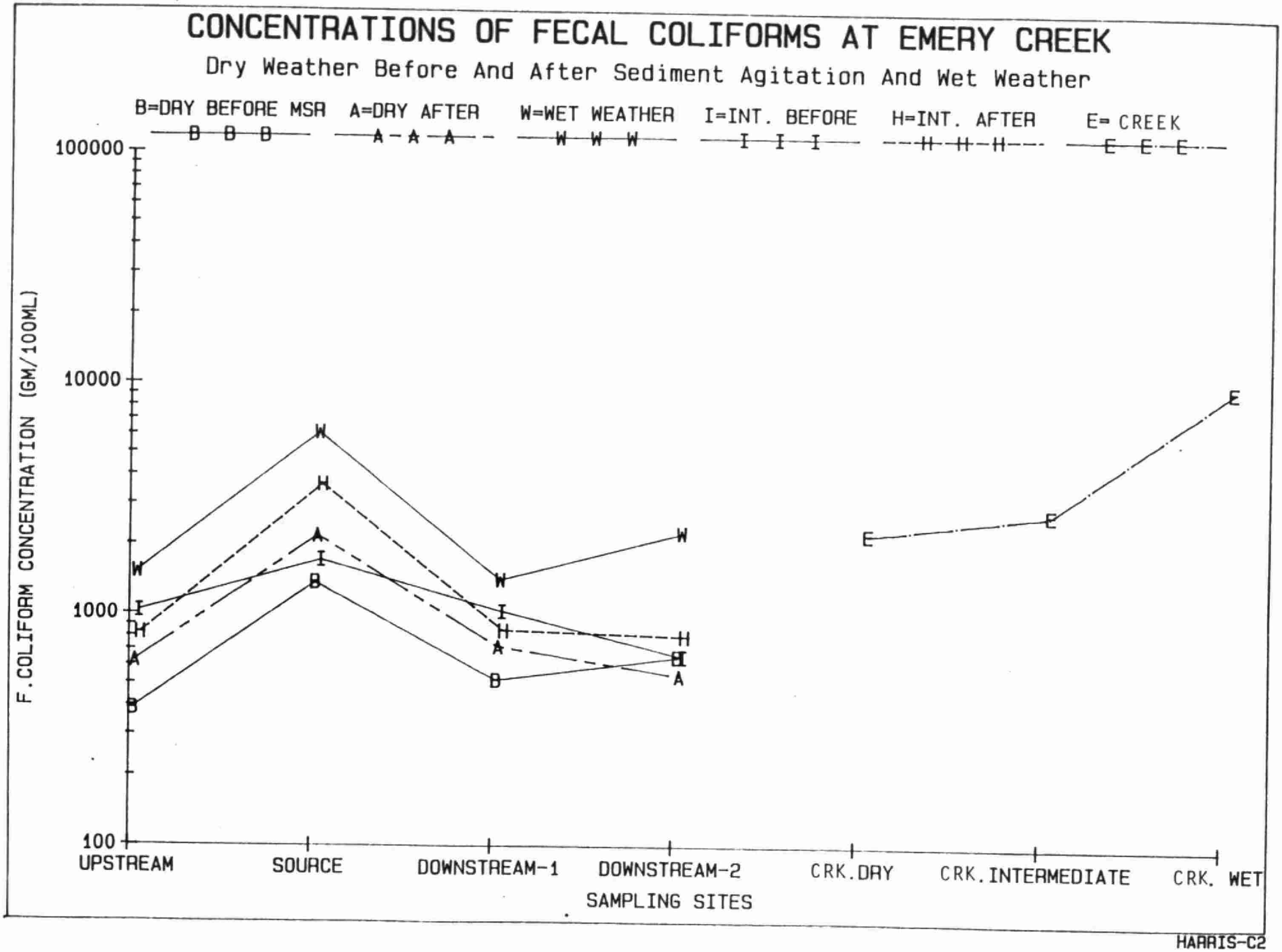
Intermediate conditions result in decreased loadings from upstream and less dilution from Emery Creek despite its lower S.SED levels. Possibly the flow has decreased proportionally more in the Creek than the river. With the exception of UP which has a higher level of SED accumulation, MSR indicates that if some sedimentation is taking place at the other three sites, it is insufficient to increase S.SED levels significantly. Under wet weather conditions there appears to be an overall decrease in the sediment deposit from source to DN2, probably as a result of resuspension during high flows.

Bacteria

Examination of the FIB concentrations (Fig. 25 to 29 and Table 15) before MSR, demonstrates the impact of Emery Creek at source under all weather conditions examined. The somewhat muted response of FC (Fig. 25), EC (Fig. 26) and PSA (Fig. 29) during intermediate conditions is again probably related to a relatively larger decrease in loadings to source from Emery Creek in comparison to upstream. The reason for the zero decrease in ENT (Fig. 28) between source and DN1, while FS (Fig. 27) levels do decline, may be related directly to inputs of more environmentally adapted ENT from Emery Creek, but there is no way to establish this from the data.

The application of MSR also demonstrates a major build up of FIB under both dry and intermediate conditions at source despite the minimal SED deposition following wet weather. The small

Figure 25.



CONCENTRATIONS OF FECAL COLIFORMS AT EMERY CREEK
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E= CREEK
100000
10000
1000
100
F.COLIFORM CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CRK.DRY
CRK.INTERMEDIATE
CRK. WET
SAMPLING SITES
HARRIS-C2

Figure [redacted] :

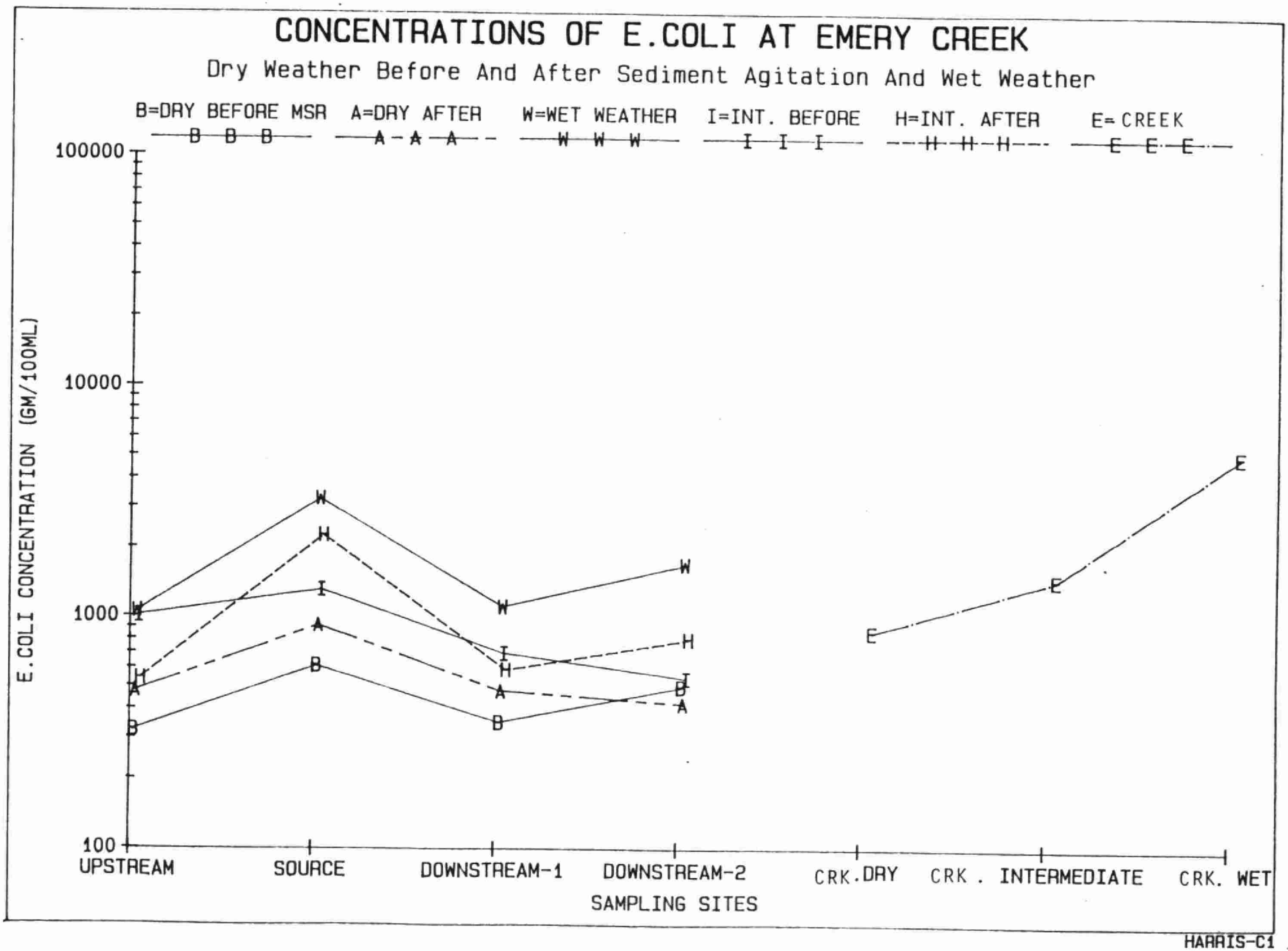
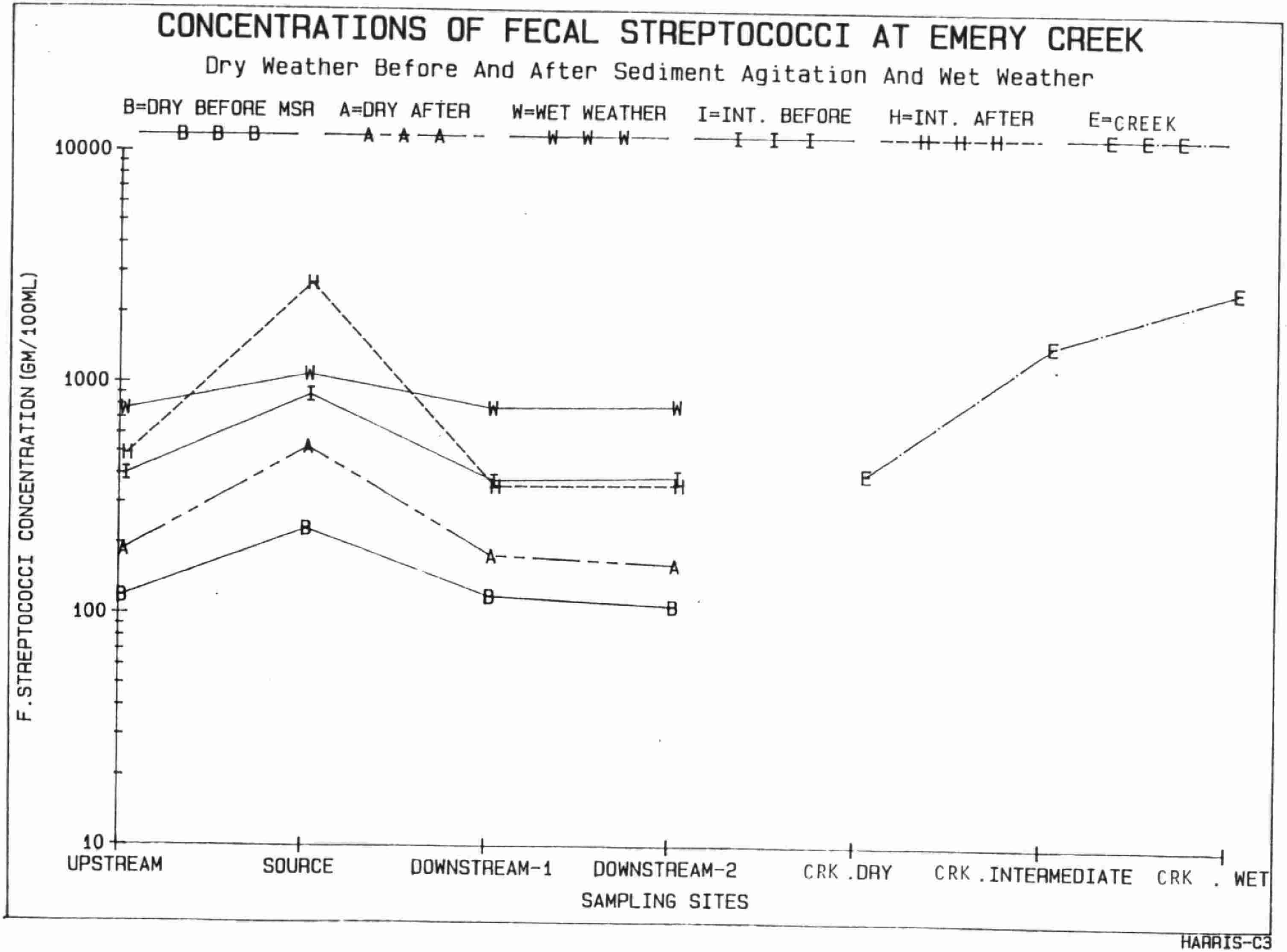
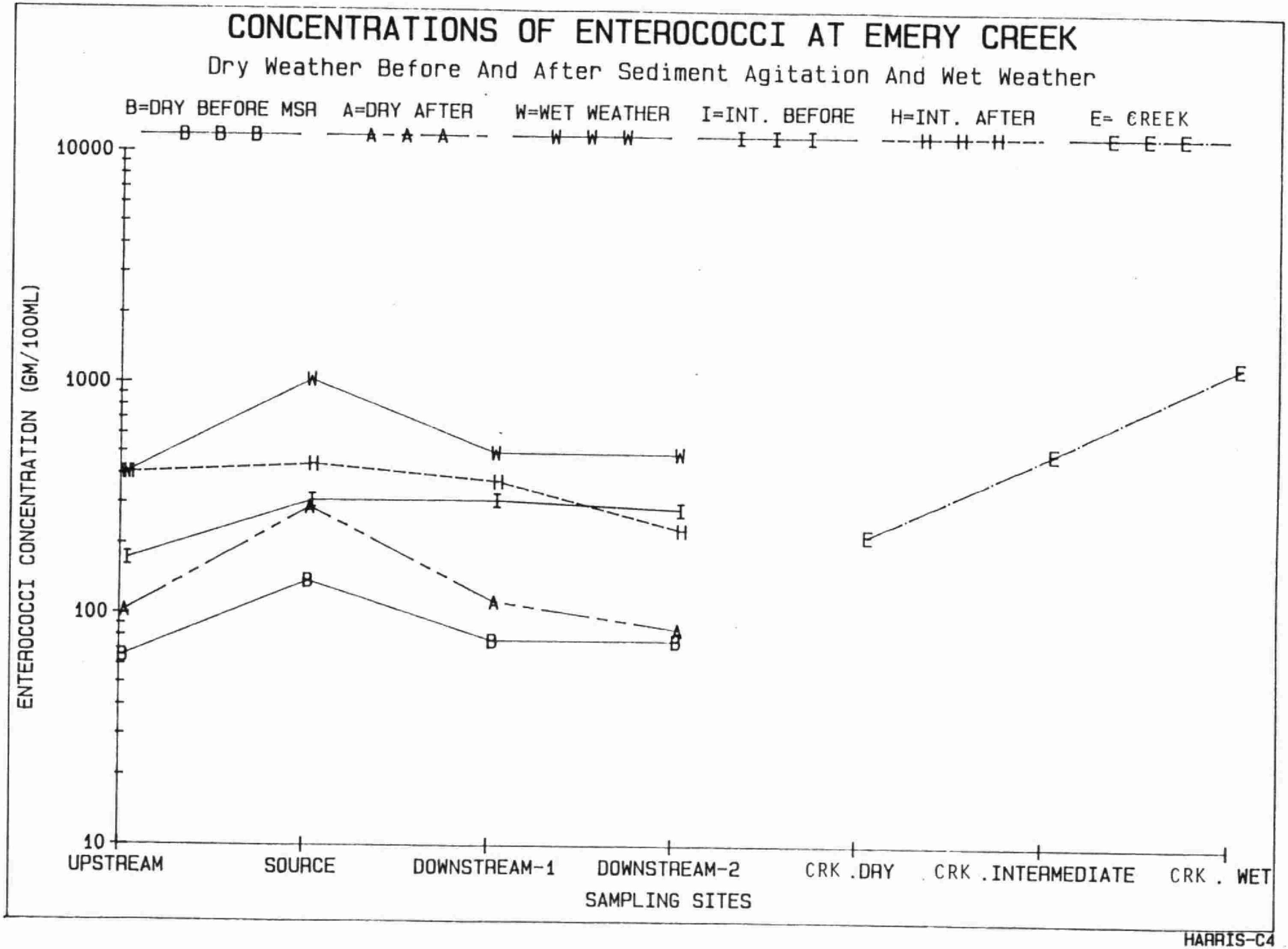


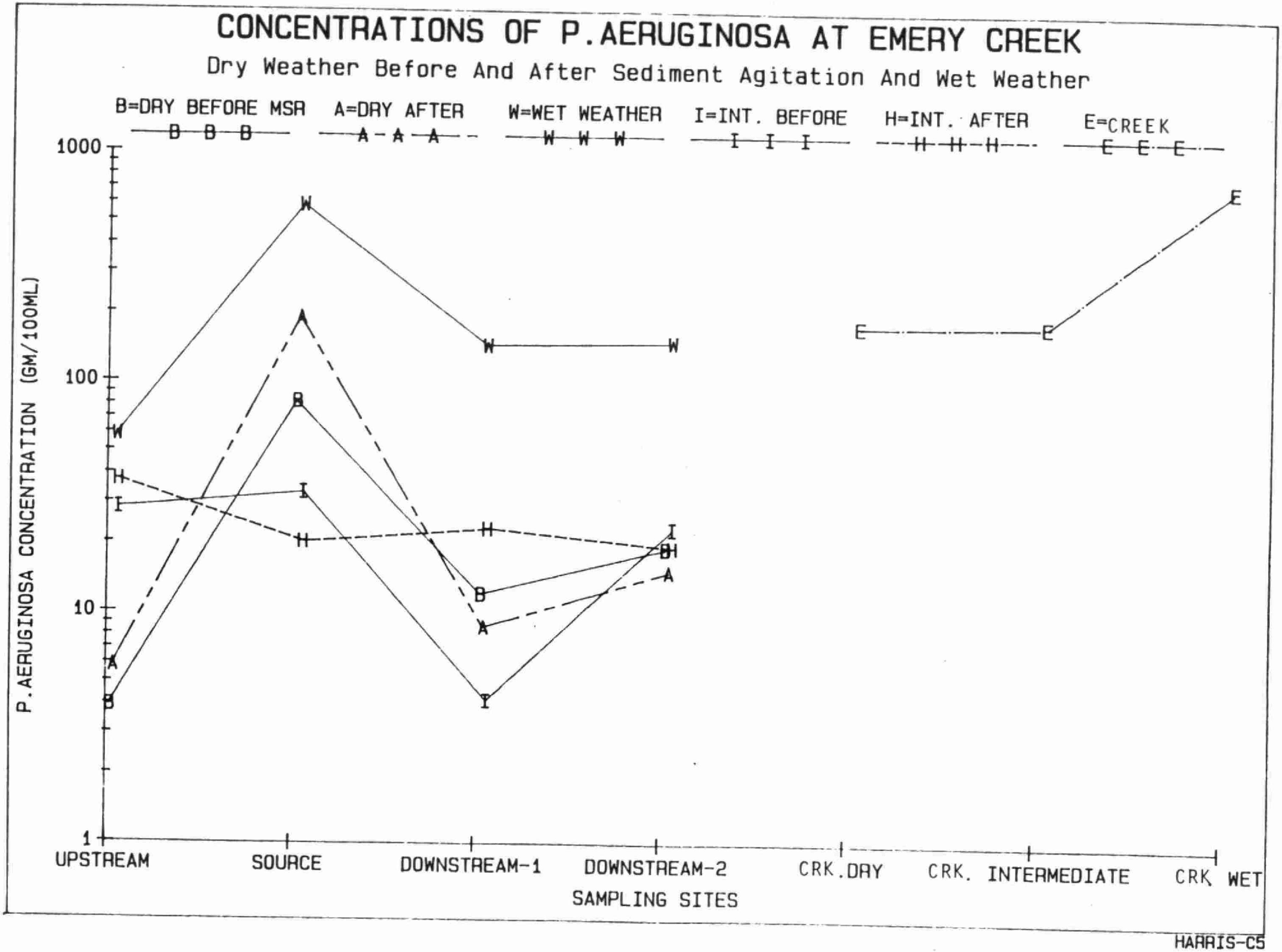
Figure 27:


CONCENTRATIONS OF FECAL STREPTOCOCCI AT EMERY CREEK
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=CREEK
F.STREPTOCOCCI CONCENTRATION (GM/100ML)
10000
1000
100
10
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CRK .DRY
CRK .INTERMEDIATE
CRK . WET
SAMPLING SITES
HARRIS-C3

[redacted]



CONCENTRATIONS OF ENTEROCOCCI AT EMERY CREEK
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E= CREEK
ENTEROCOCCI CONCENTRATION (GM/100ML)
10000
1000
100
10
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CRK .DRY
CRK .INTERMEDIATE
CRK . WET
SAMPLING SITES
HARRIS-C4



CONCENTRATIONS OF P.AERUGINOSA AT EMERY CREEK
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=CREEK
P.AERUGINOSA CONCENTRATION (GM/100ML)
1000
100
10
1
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CRK.DRY
CRK. INTERMEDIATE
CRK WET
SAMPLING SITES
HARRIS-C5

accumulation of ENT and decrease in PSA between UP and source could result from deposition of upstream sediments carrying significantly lower concentrations of these bacteria as opposed to the other FIB.

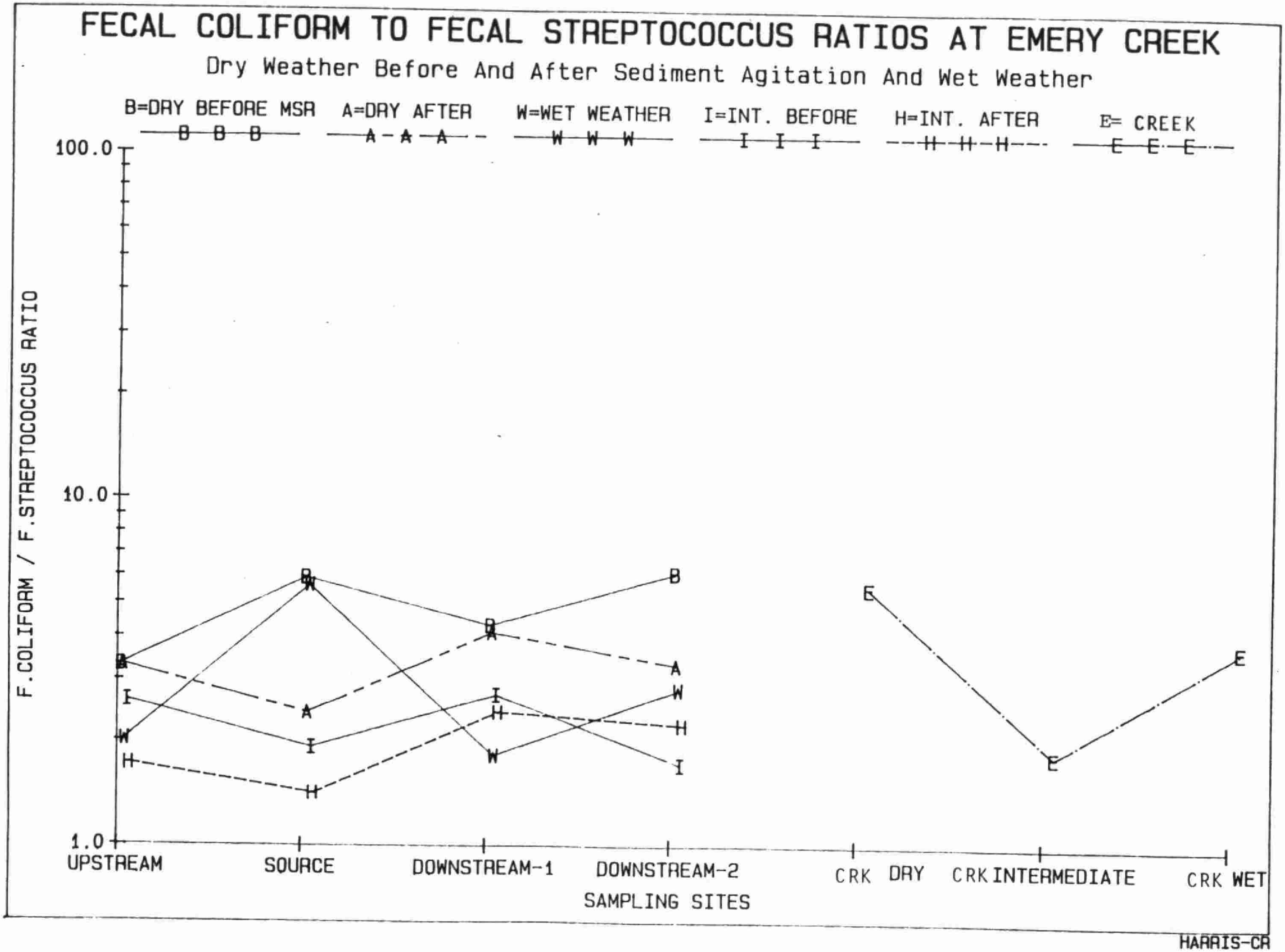
The high levels of PSA in Emery Creek could be due to inputs from point sources such as SSO's. Analyses of the Creek upstream demonstrated lower PSA concentrations than at the mouth. Thus it is possible that the PSA levels at the mouth of Emery Creek are the result of regrowth of PSA inputs upstream, possibly due to increased nutrient input and the higher creek temperature. The potential of Peudomonads to regrow under favourable environmental conditions has been shown (41). A further examination of the potential for PSA regrowth in Emery Creek would be needed to verify if this is in fact occurring.

Despite the difference in density fluctuations for the different FIB it is readily apparent that this input (Emery Creek) is a significant one, causing an obvious impact on the already polluted Humber River.

<u>FC/FS</u>

The FC/FS ratios in the water column (Fig. 30 and Table 15) are also indicative of an impact from Emery Creek. During dry and wet weather when FC/FS in the creek is above that in the Humber River the ratio increase at source while during intermediate conditions the reverse is true. Although increased fecal inputs are indicated, the ratios are at all times indicative of

Figure 90.



FECAL COLIFORM TO FECAL STREPTOCOCCUS RATIOS AT EMERY CREEK
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E= CREEK
F.COLIFORM / F.STREPTOCOCCUS RATIO
100.0
10.0
1.0
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
CRK DRY
CRK INTERMEDIATE
CRK WET
SAMPLING SITES
HARRIS-CR

mixed origins. The increase in FC/FS at DN2 could be the result of resuspension of SED from the DN1 area where ratios tended to be higher than source. The higher ratio at DN1, following MSR, despite the obviously greater impact at source is related to the creek input. It would appear that there is a greater impact from upstream S.SED on deposits in the source area. There S.SED may be carrying less or older fecal inputs and have proportionally higher FS levels than Emery Creek. Their sedimentation at source would tend to reduce FC/FS ratios.

Post-Rainfall Bacterial (EC/FC) Quality

During wet weather (day 0), the EC to FC ratios (Table 16) are generally low indicating that the inputs during a storm are dominated by less recent fecal and non-fecal material. There is a slight increase in the ratio at source and downstream suggesting that there is an influence from the creek. The geometric mean EC to FC ratios indicate that under average wet weather conditions, the main impact of the creek is at source.

The EC to FC ratios obtained during intermediate and dry weather indicate that most of the input of recent fecal pollution comes from upstream. This is also evidenced by the geometric mean ratios (Table 15).

Even though the creek outflow exhibits very high levels of FIB, the EC to FC ratios remain low during all weather conditions. This would suggest that the fecal pollution input to the creek is occurring somewhere upstream; a fact which is

Table 16 :

Escherichia Coli to Fecal Coliform Ratios
during Post-Rainfall Period at Emery Creek

Site	Number of Days Following Rainfall 0	1	2	3	4
UB	11000/35000 (0.31)	518/655 (0.79)	584/634 (0.92)	328/336 (0.98)	359/427 (0.84)
UA		714/807 (0.88)	428/599 (0.71)	336/372 (0.90)	708/996 (0.71)
SB	21000/39000 (0.54)	1226/2120 (0.58)	1406/2024 (0.69)	340/530 0.64)	618/1853 (0.33)
SA		1473/3126 (0.47)	1846/3274 (0.56)	340/1050 (0.32)	1129/3204 (0.35)
DN1B	19000/42000 (0.45)	529/595 (0.89)	460/641 (0.72)	192/356 (0.54)	458/744 (0.62)
DN1A		773/912 (0.85)	507/684 (0.74)	510/670 (0.76)	618/1100 (0.56)
DN2B	10000/20000 (0.50)	871/1069 (0.81)	486/549 (0.89)	384/412 (0.93)	626/953 (0.66)
DN2A		882/931 (0.95)	664/760 (0.87)	339/340 (1.0)	441/635 (0.69)
CREEK	19000/39000 (0.49)	1989/3254 (0.61)	3140/3142 (1.0)	520/860 (0.60)	1007/3663 (0.27)

E. coli / F. Coliforms (Ratio)

*approximate value

supported by the levels of P. aeruginosa recovered from the creek mouth (see Discussion of Fig. 29). The one exception to the low creek ratios occurs during day 2 (Table 16) when the EC to FC ratio is 1.0. Normally the flow in the creek is low and fecal inputs would not be rapidly transported downstream. However, as previously mentioned, illegal dumping by industries located in upper creek area is thought to occur from time to time causing the flow rate in the creek to increase. These rapid flows would facilitate quicker deportation of fecal material downstream which would account for the increased EC to FC ratio and FIB levels at the creek mouth if this process had occurred during or just prior to the day 2 sampling.

The FC and EC levels and the EC to FC ratios at source appear to be influenced somewhat more by the pollution loading from the creek (Table 15 and 16), while the DN2 station seems to be impacted upon more by upstream inputs as reflected by the similar EC to FC ratios exhibited at this site and upstream (Table 15 an 16). The DN1 site is affected by a combination of both upstream and creek inputs.

The variation in the EC to FC ratio before and after MSR throughout the post-rainfall period, at all of the sites suggest that there is ongoing dry weather inputs of fecal material to the system, however, the inputs appear to be more recent upstream than in the creek or at source.

Natural Environmental Phenomena and Bacterial Concentrations

The data, as stated earlier, is insufficient to draw specific conclusions, however, the different effects of rainfall and pollution input can be observed (Figs. 31 and 32). The small rainfall during the first survey (Fig. 10A and 10B) causes only a small change in flow while increasing bacterial loadings and having a scouring effect on sediment. An effect by rainfall on flow, bacterial levels and SED can also be observed during the fifth survey. The decreasing flows following rainfall (second and sixth surveys) result in decreasing bacterial concentrations while SED is slower to react. The increases in bacterial densities observed during periods of decreasing flow (third and fourth surveys) could be the result of intermittent pollution inputs. Emery Creek was observed to increase flow during dry weather probably as a result of illegal dumping of various wastes. The increased flow could very well cause an impact on the Humber River by temporarily increasing pollutant loadings. High concentrations of pollutants in the creek could result in increasing levels in the Humber River without affecting the flow.

The complexity of the location is further demonstrated by the observed changes in FC and EC densities which do not always coincide suggesting different combinations of inputs at different times. Decreases in the EC/FC ratio between day 2 and day 3 of the fourth survey and day 1 and day 2 of the fifth survey indicate a shift to less recent fecal inputs and thus a probable shift in the source(s) of the major pollution contributions.

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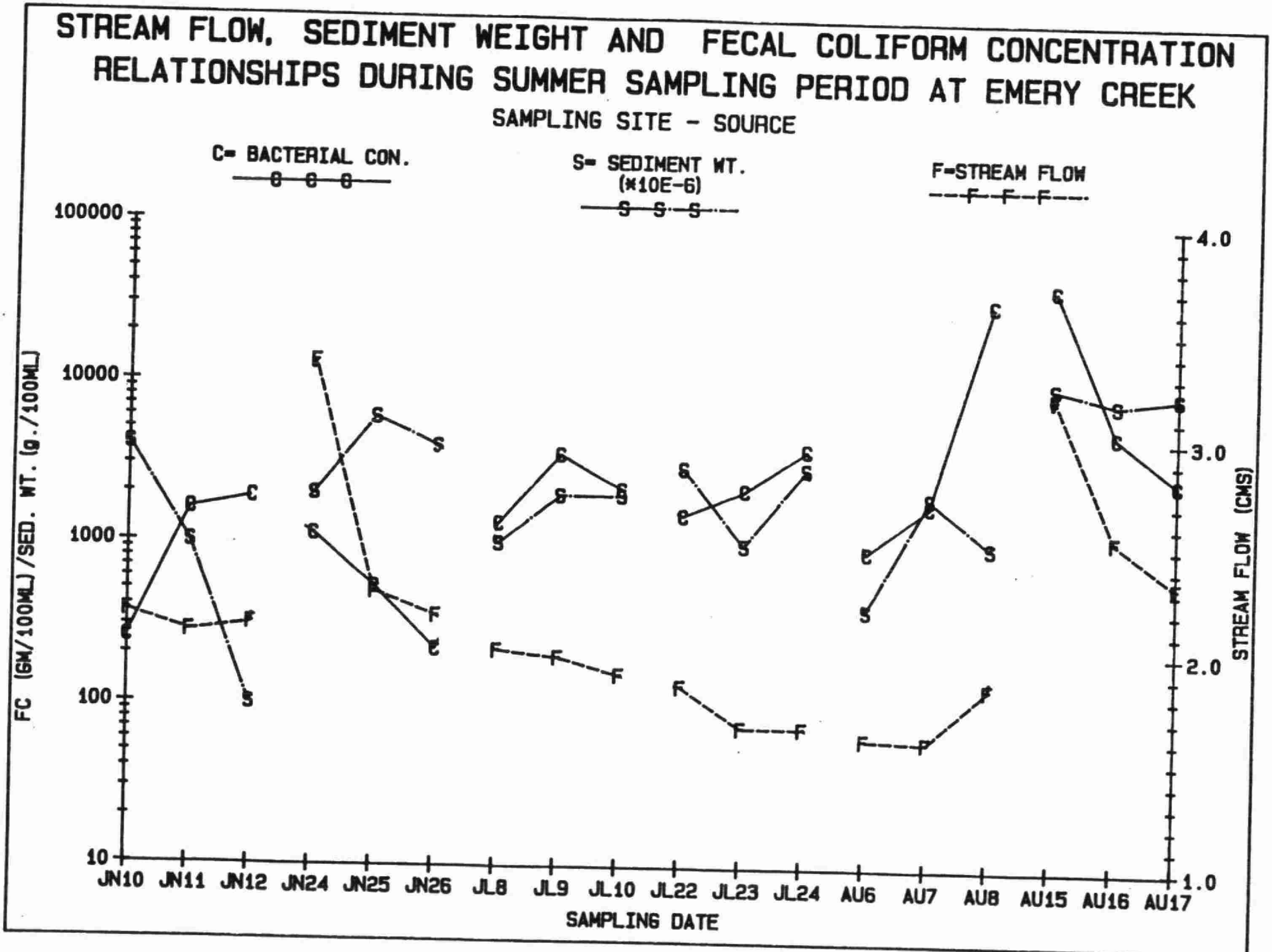
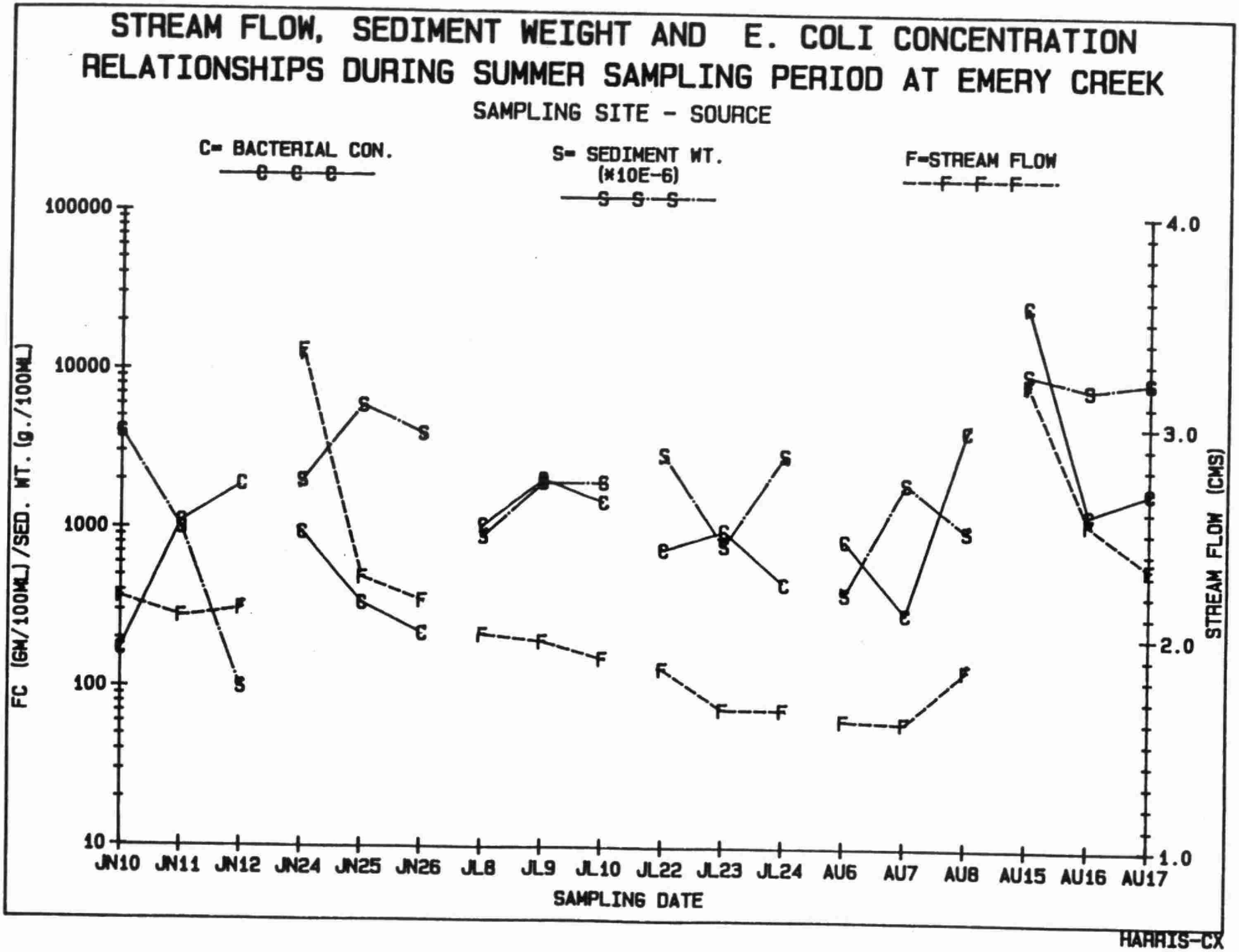


HARRIS-CC

Figure 32:


STREAM FLOW, SEDIMENT WEIGHT AND E. COLI CONCENTRATION RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT EMERY CREEK
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT. (*10E-6)
F=STREAM FLOW
FC (GM/100ML)/SED. WT. (g./100ML)
STREAM FLOW (CMS)
100000
10000
1000
100
10
4.0
3.0
2.0
1.0
JN10 JN11 JN12 JN24 JN25 JN26 JL8 JL9 JL10 JL22 JL23 JL24 AU6 AU7 AU8 AU15 AU16 AU17
SAMPLING DATE
HARRIS-CX

The sediment/sediment regression analyses (Table 17) demonstrates similar factors impacting at all sites, however, the poorer correlations with upstream S.SED levels suggests that the Emery Creek inflow is having a major effect on SED.

The EC/FC regression analyses (Table 18) also shows the impact of Emery Creek on bacterial levels. However, this impact appears to give way to the prevailing Humber River conditions (upstream) more rapidly than SED, as seen by the correlation coefficients at DN2.

The bacterial/sediment regression analyses show an increasing correlation between EC/FC levels at all sites with SED in a downstream direction. This could indicate a gradual melding of the different factors (upstream vs. Emery Creek) acting on bacteria and SED, possibly due to the inevitable incorporation of Emery Creek inputs into the main Humber River.

Flow in the Humber River has a positive correlation with the SED levels at all sites while this only occurs at UP with EC and FC. This is probably due to the somewhat longer impact of the creek on bacterial levels as observed earlier (Figs. 31 and 32).

Streptococcus Populations

The predominance at UP of S. faecalis var liquefaciens and S. durans as compared to S. faecium along with the presence of S. faecalis var zymogenes and S. faecium var casseliflavus indicates mixed sources of input dominated by non-human inputs (Table 19). The basic lack of heterogeneity and high proportion of S. durans

Table 17:

Correlation Coefficients of Suspended Sediment Weights
(Before Sediment Agitation) with Fecal Coliform, Escherichia Coli
Counts and Flow Rate at
Emery Creek

Sediment Weight	Sediment Weight			
	Upstream	Source	Downstream I	Downstream II
Upstream	+1.00	+0.61	+0.62	+0.64
Source		+1.00	+0.94	+0.83
Downstream I			+1.00	+0.89
Downstream II				+1.00
Fecal coliforms				
Upstream	+0.54	+0.58	+0.72	+0.80
Source	+0.11	+0.30	+0.47	+0.56
Downstream I	+0.45	+0.45	+0.56	+0.69
Downstream II	+0.41	+0.46	+0.59	+0.72
E. coli				
Upstream	+0.52	+0.60	+0.72	+0.78
Source	+0.31	+0.44	+0.64	+0.72
Downstream I	+0.53	+0.52	+0.64	+0.75
Downstream II	+0.43	+0.48	+0.61	+0.69
Flow rate	+0.81	+0.61	+0.87	+0.60

Table 18:

Correlation Coefficients of Fecal Coliform, Escherichia coli Counts and Flow Rate at Emery Creek

E. coli	Fecal Coliforms Upstream	Fecal Coliforms Source	Fecal Coliforms Downstream I	Fecal Coliforms Downstream II
Upstream	+0.99	+0.70	+0.77	+0.85
Source	+0.80	+0.86	±0.57	+0.74
Downstream I	+0.84	+0.63	+0.98	+0.76
Downstream II	+0.84	+0.76	+0.75	+0.97
Fecal coliforms				
Upstream	+1.00	+0.72	+0.82	+0.87
Source		+1.00	+0.62	+0.78
Downstream I			+1.00	+0.76
Downstream II				+1.00
Flow rate	+0.61	+0.28	+0.44	+0.41
E. coli	**E. coli**			
Upstream	+1.00	+0.78	+0.79	+0.82
Source		+1.00	+0.62	+0.76
Downstream I			+1.00	+0.75
Downstream II				+1.00
Flow rate	+0.60	+0.53	+0.55	+0.46

Table 19:

Fecal Streptococcus Populations at Emery Creek Under Wet and Dry Weather Conditions

Site	cond.	Total Isolates	S.faecalis faecalis	S.faecalis liquefaciens	S.faecalis zymogenes	S.faecium	S. faecium casseliflavus	S.durans	S.bovis	S.avium	Fecal Strep.	Non-fecal streptococci	Aerococcus
UPSTRM	Dry Before	18	1(5.6)	6(33.3)	1(5.6)	3(16.7)	2(11.1)	5(27.8)	-	-	-	-	-
	Dry After	16	-	5(31.3)	-	-	1(6.3)	10(62.5)	-	-	-	-	-
	Wet	25	2(8.0)	7(28.0)	-	2(8.0)	10(40.0)	4(16.0)	-	-	-	-	-
SOURCE	Dry Before	16	-	1(6.3)	-	3(18.8)	10(63.5)	2(13.5)	-	-	-	-	-
	Dry After	13	-	1(7.7)	-	-	3(23.1)	6(46.2)	-	2(15.4)	-	-	1(7.7)
	Wet	35	-	7(20.0)	-	12(34.3)	9(25.7)	5(14.3)	-	-	2(5.7)	-	-
DOWNSTRM	Dry Before	19	-	3(15.8)	-	1(5.3)	11(57.9)	4(21.1)	-	-	-	-	-
	Dry After	9	-	2(22.2)	-	-	4(44.4)	2(22.2)	1(11.1)	-	-	-	-
	Wet	34	-	7(20.6)	-	12(35.3)	6(17.6)	4(11.8)	-	-	3(8.8)	2(5.9)	-
CREEK	Dry Before	13	-	1(7.7)	-	5(38.5)	5(38.5)	2(15.4)	-	-	-	-	-
	Dry After	NS	-	-	-	-	-	-	-	-	-	-	-
	Wet	17	-	-	1(5.9)	6(35.3)	7(41.2)	3(17.6)	-	-	-	-	-
Total column		215	3	40	2	44	48	47	1	2	5	2	1

Percentages in Parenthesis ( )

in relation to the other species present, following MSR, is even more suggestive of a dominant non-human fecal impact. Wet weather streptococci populations at UP are also in line with a proportionally increased non-human impact.

The streptococcal species distribution at source shows the impact of an input that appears to contain slightly more human fecal material (S. faecium) and less diversity in the non-human sources as evidence by the dominance of S. faecium var casseliflavus. This shift in population, although not identical to the populations in Emery Creek, is certainly in keeping with the observations made within the restrictions imposed by this study. Under wet weather conditions, however, the data is somewhat contradictory in that the relative impact of human waste appears to increase at source while little change is apparent in the outflow of the creek. The relatively high level of S. faecium and reduction in S. faecalis var liquefaciens from UP suggest the impact is from Emery Creek. The fact that the portion of water sampled at UP or Emery Creek is unlikely to be sampled at source will undoubtedly lead to differences in results in a dynamic system.

MSR at source during dry weather demonstrates a predominantly non-human impact as at UP but the shift in population indicates some of the SED as from the creek as well as upstream. The presence of S. avium and Aerococcus sp. could indicate inputs from bird sources such as pigeons or even some animals such as muskrats.

The observations of streptococcus populations at DN1 basically reflect the same impact as at source with an increasing effect, probably due to gradual assimilation by the main Humber flow, from upstream. The presence of S. bovis is most likely due to inputs from dogs.

Bacterial Survival

The die-off rates determined at the Emery Creek source site during the summer (Fig. 33 and 34, and Table 20) indicate that S. faecalis decreases more rapidly than E. coli, an observation that was also made at Elhart Drive. The natural conditions or types of pollutants present in the water column that would lead to the existence of an environment harsher to S. faecalis than E. coli is not known but may be related to chemical pollutants (Dufour 1985, personal communication).

The apparent increase in E. coli between day 2 and day 3 should be considered to be anomalous due most likely to problems such as instream contamination or sampling difficulties. The conditions present in the Humber River are simply not suitable for the growth of this bacterium. An additional run done with larger chambers (Fig. 34) did in fact show a continued decline to extinction of E. coli and Klebsiella pneumoniae over the three day exposure. However, this decline may be more rapid in the large chamber due to the increased surface area to volume ratio. The use of the larger chambers with S. faecalis and S. faecium continued to show the more rapid die-off of S. faecalis.

Table 20:

Percent die-off of fecal indicator bacteria at Emery Creek
during summer weather conditions (Average water temperature 20.5°C)

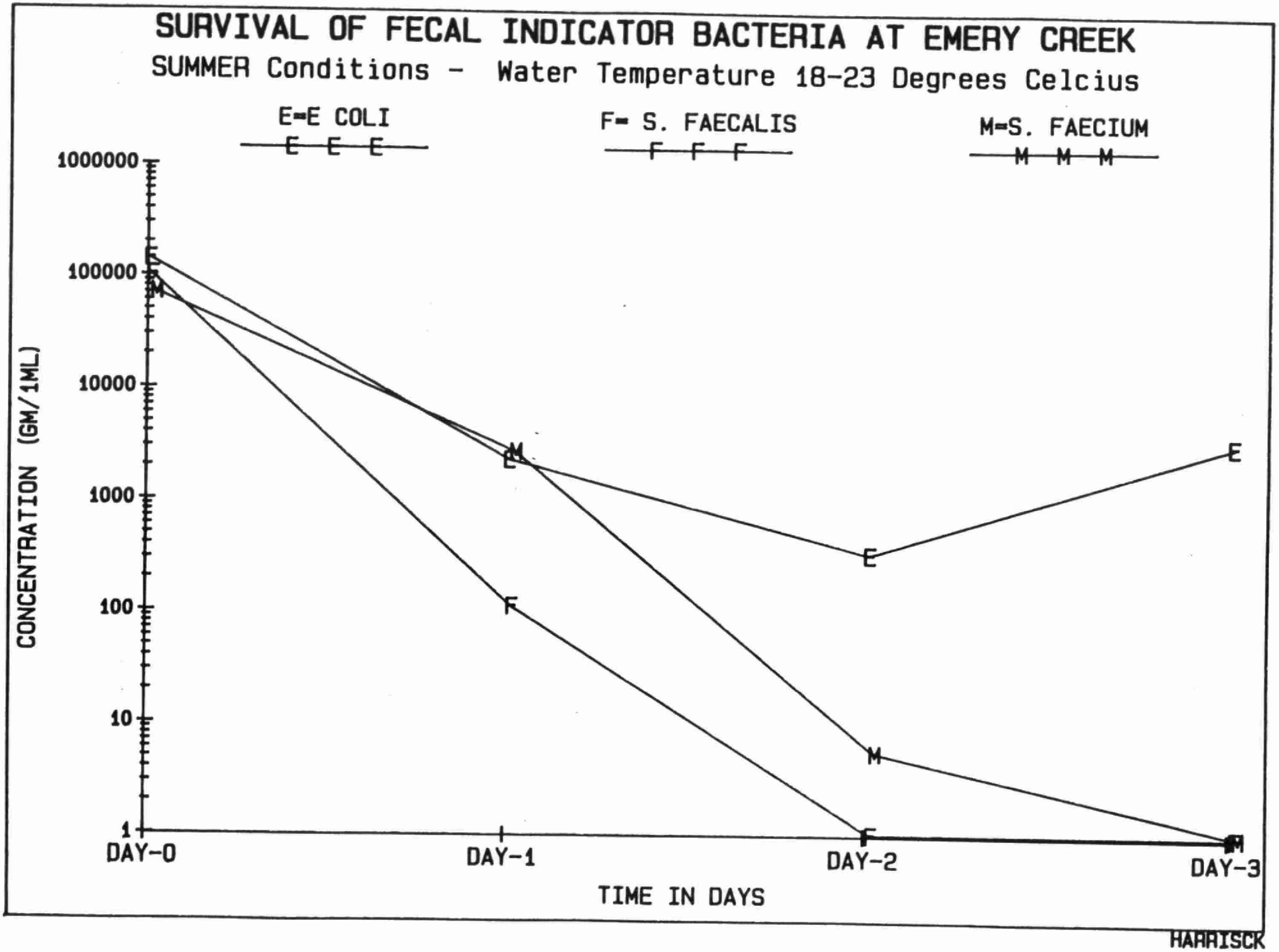
Bacterial Culture	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli (50 ml chamber)	1.4×10^5	2.3×10^3	3.3×10^2	3.3×10^3
Escherichia coli (100 ml chamber	1.01×10^5	2.1×10^2	8.0	1
Klebsiella pneumoniae (100 ml chamber)	1.14×10^5	1.5×10^2	7.0	1
Strep. faecalis (50 ml chamber)	1.0×10^5	1.1×10^2	1	1
Strep. faecalis (100 ml chamber	1.0×10^5	1.0×10^2	1	1
Strep. faecium (50 ml chamber)	7.0×10^4	2.65×10^3	5.2	1
Strep. faecium (100 ml chamber)	7.0×10^4	2.7×10^3	5.4	<1

Table 21:

Percent die-off of fecal indicator bacteria at Emery Creek
during winter weather conditions (Average water temperature 2.5°C)

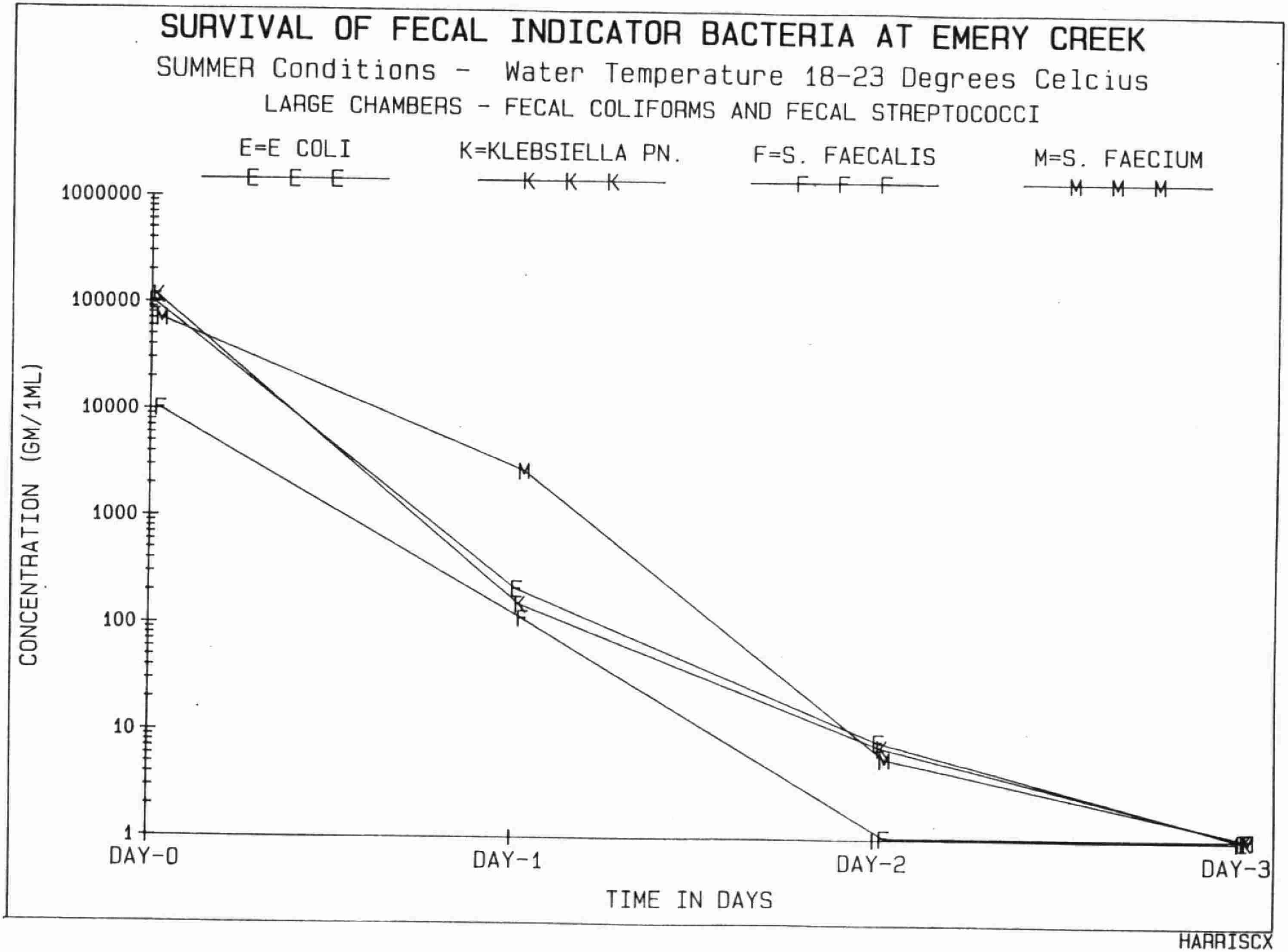
Bacterial Culture (50 ml chamber)	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli	1.6×10^5	1.8×10^4	1.9×10^4	2.8×10^3

Figure 33:



SURVIVAL OF FECAL INDICATOR BACTERIA AT EMERY CREEK
SUMMER Conditions - Water Temperature 18-23 Degrees Celcius
E=E COLI
F= S. FAECALIS
M=S. FAECIUM
CONCENTRATION (GM/1ML)
1000000
100000
10000
1000
100
10
1
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISCK

Figure 34.


SURVIVAL OF FECAL INDICATOR BACTERIA AT EMERY CREEK
SUMMER Conditions - Water Temperature 18-23 Degrees Celcius
LARGE CHAMBERS - FECAL COLIFORMS AND FECAL STREPTOCOCCI
E=E COLI
K=KLEBSIELLA PN.
F=S. FAECALIS
M=S. FAECIUM
1000000
100000
10000
1000
100
10
1
CONCENTRATION (GM/1ML)
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISCX

S. faecium, although appearing more resistant to environmental exposure during the first 24 hrs., could not be recovered on the third day.

Unfortunately major field problems prevented the collection of winter data except for *E. coli* (Fig. 35, Table 21) thus a comparison of the effect of the colder water temperatures on the different bacteria is not possible. If one considers the data from the larger chambers to be valid for the summer then the survival of *E. coli* appears to be greatly enhanced.

James Garden - (Waterfowl Roosting Area)

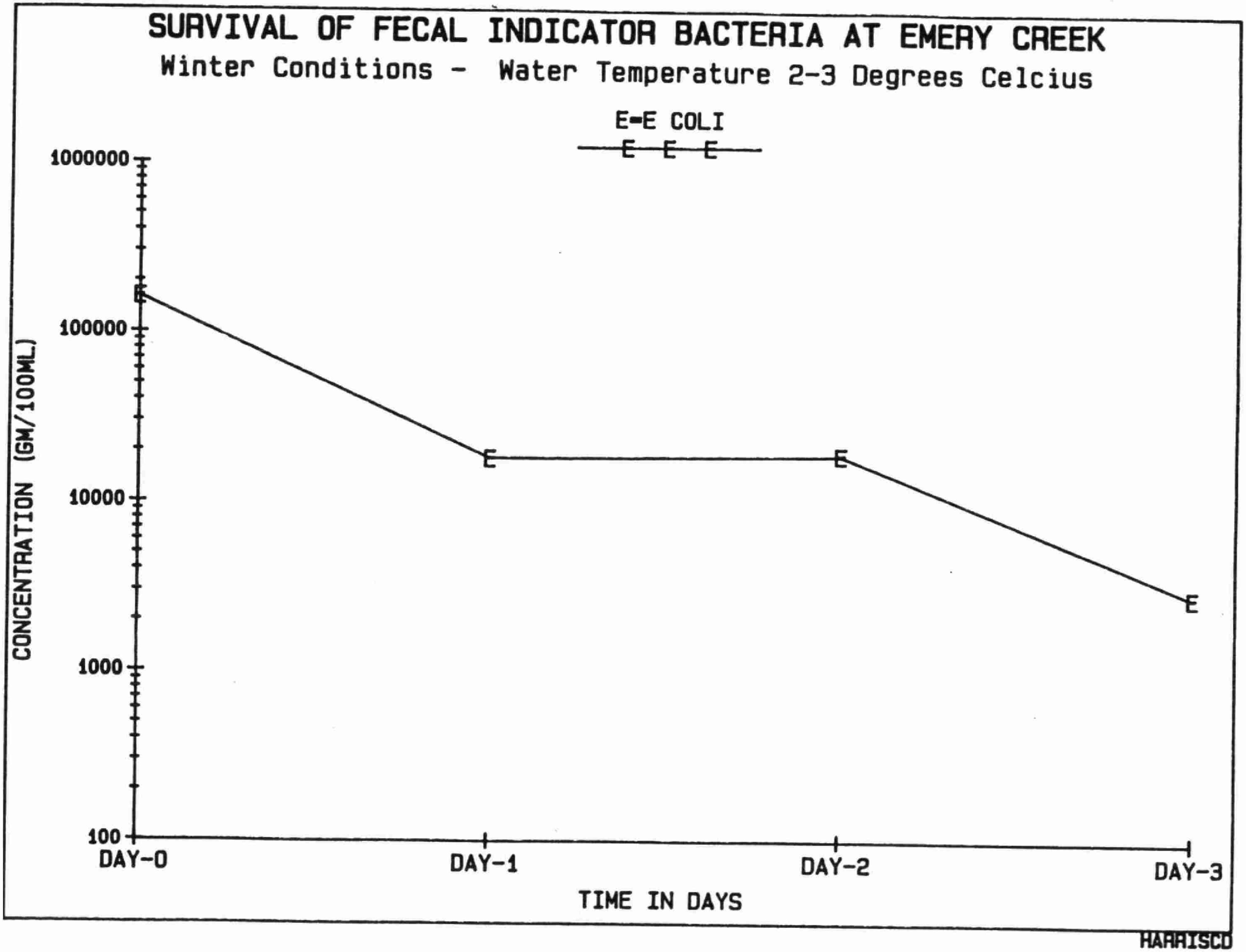
Sediment Resuspension

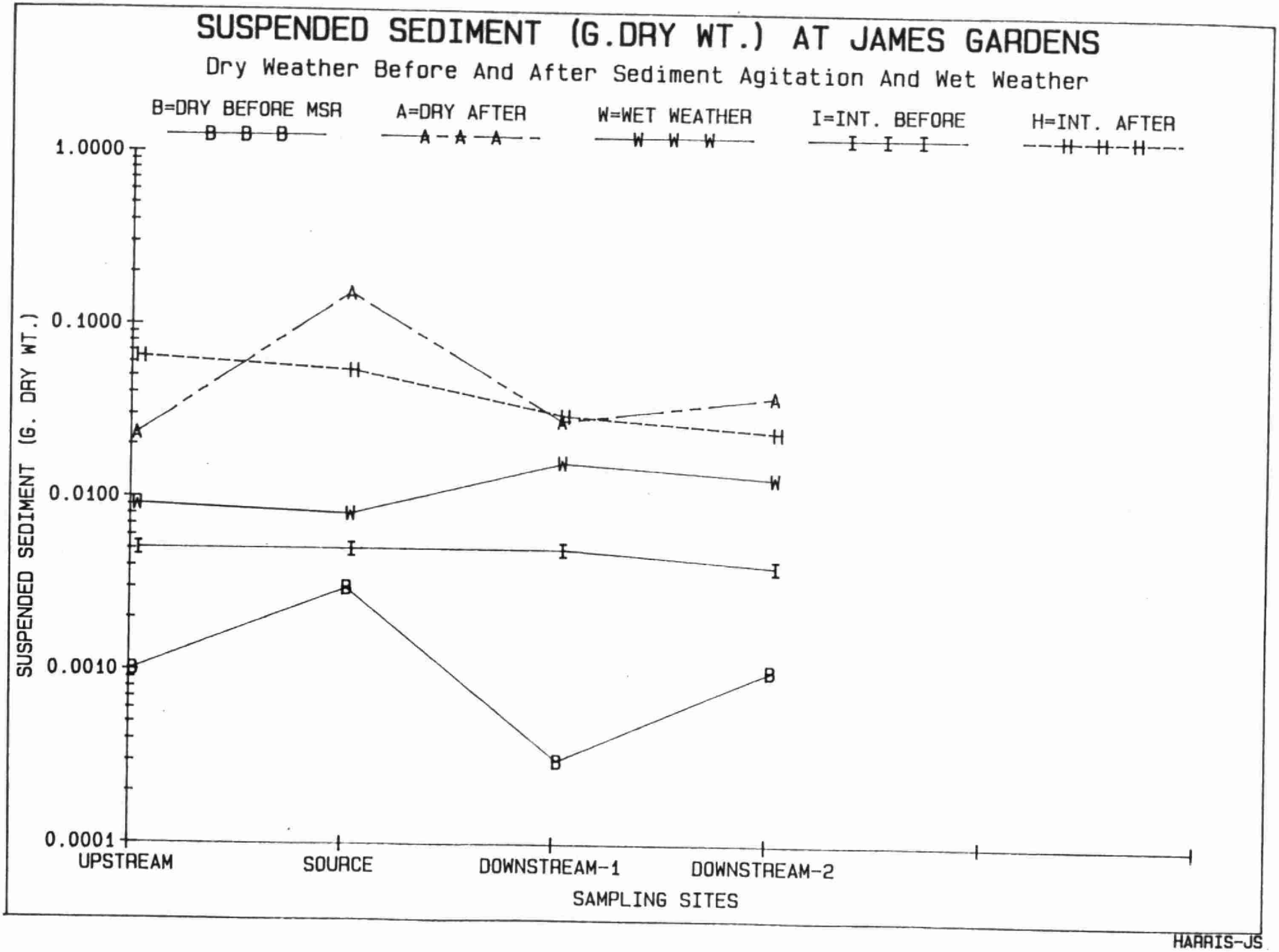
Sediment

The SED concentrations during dry weather (Fig. 36 and Table 22), before MSR, appeared to indicate deposition at DN1. Although a great deal of SED accumulation is occurring throughout this location, it is highest at source. The dual high in water column and sediment is due to the heavy direct loadings from the large gull populations in the area. The increase in SED at DN2 may be due to resuspension occurring at the sites upstream with re-deposition at DN2.

It is of interest to note that although wet weather SED water column levels are higher than those during dry weather they are consistently lower than those obtained during dry and intermediate conditions following MSR. This is a further indication of the high potential for sedimentation in this area.

Figure 35:


SURVIVAL OF FECAL INDICATOR BACTERIA AT EMERY CREEK
Winter Conditions - Water Temperature 2-3 Degrees Celcius
E=E COLI
CONCENTRATION (GM/100ML)
1000000
100000
10000
1000
100
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISCD



SUSPENDED SEDIMENT (G.DRY WT.) AT JAMES GARDENS
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
SUSPENDED SEDIMENT (G. DRY WT.)
1.0000
0.1000
0.0100
0.0010
0.0001
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SAMPLING SITES
HARRIS-JS

Table 22:

Geometric mean concentrations of Fecal Indicator Bacteria, E. coli to Fecal Coliform ratios, Fecal Coliform to Fecal Streptococci Ratios and Suspended Sediment Weights During Dry and Intermediate Weather (Before and After Sediment Agitation) and Wet Weather at James Gardens

Sampling site and weather cond.		Fecal coliforms	E. coli	Fecal Streptococci	Enterococci	P. aeruginosa	EC/FC Ratio	FC/FS Ratio	Suspended sediment (grams/100mls)
		(per 100 ml water sample)							
upstream	B	412	301	106	90	2.5	0.73	3.9	0.001
dry	A	638	466	142	162	4.8	0.73	4.5	0.023
Int.	B	645	589	288	88	14	0.91	2.2	0.005
	A	1,394	1,152	449	315	28	0.83	3.1	0.064
wet		3,548	2,591	1,781	1,332	89	0.73	2.0	0.009
source	B	379	306	61	70	2.3	0.81	6.2	0.003
dry	A	3,691	2,986	438	173	13.4	0.81	8.4	0.153
Int.	B	624	592	210	148	11	0.95	3.0	0.005
	A	1,661	1,349	538	267	28	0.81	3.1	0.054
wet		2,739	2,431	1,731	1,398	124	0.89	1.6	0.008
downstream I									
dry	B	387	320	67	33	6.3	0.83	5.8	0.003
	A	787	451	96	56	9.6	0.57	8.2	0.028
Int.	B	772	584	274	106	20	0.76	2.8	0.005
	A	1,627	1,113	378	188	25	0.68	4.3	0.030
wet		3,648	2,983	2,263	1,643	139	0.82	1.6	0.016
downstream II									
dry	B	375	245	65	48	3.7	0.65	5.8	0.001
	A	732	474	105	60	53	0.65	7.0	0.039
Int.	B	835	738	225	112	10	0.88	3.7	0.004
	A	1,989	1,608	603	265	44	0.81	3.3	0.024
wet		2,648	1,891	1,797	1,619	189	0.71	1.5	0.013

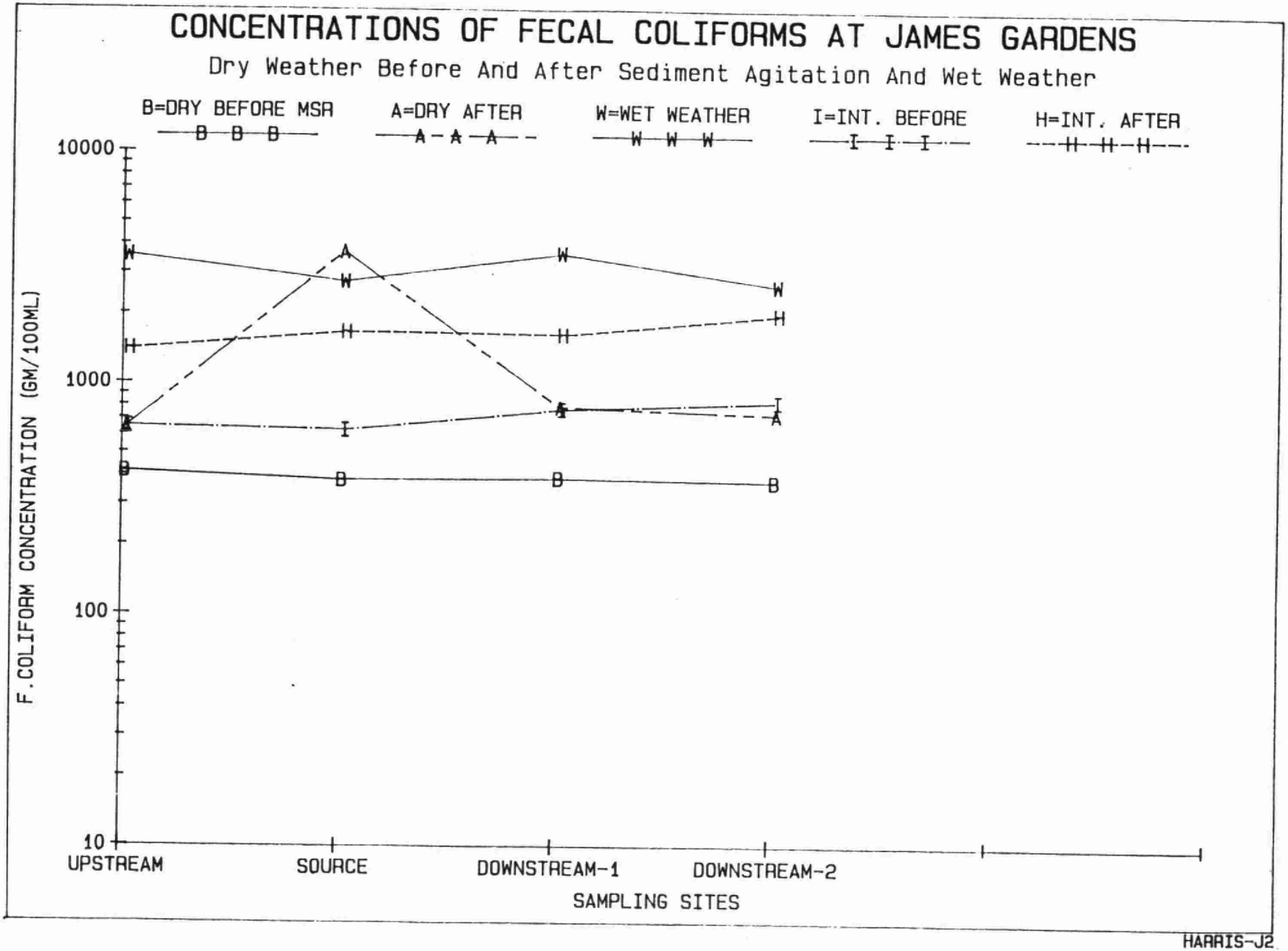
The increased SED density at DN1 during wet weather is probably due to resuspension of sediments from source. The decrease in SED at source, following MSR, during intermediate conditions also indicates resuspension and transport has occurred. There is, however, some initial build up of SED at UP as flows begin to decrease following a storm event.

The lack of any impact on SED water column levels, prior to MSR during intermediate conditions, is the result of the resuspension and transport during wet weather and the temporary absence of gulls until flows decrease re-exposing their island roosting sites.

Bacteria

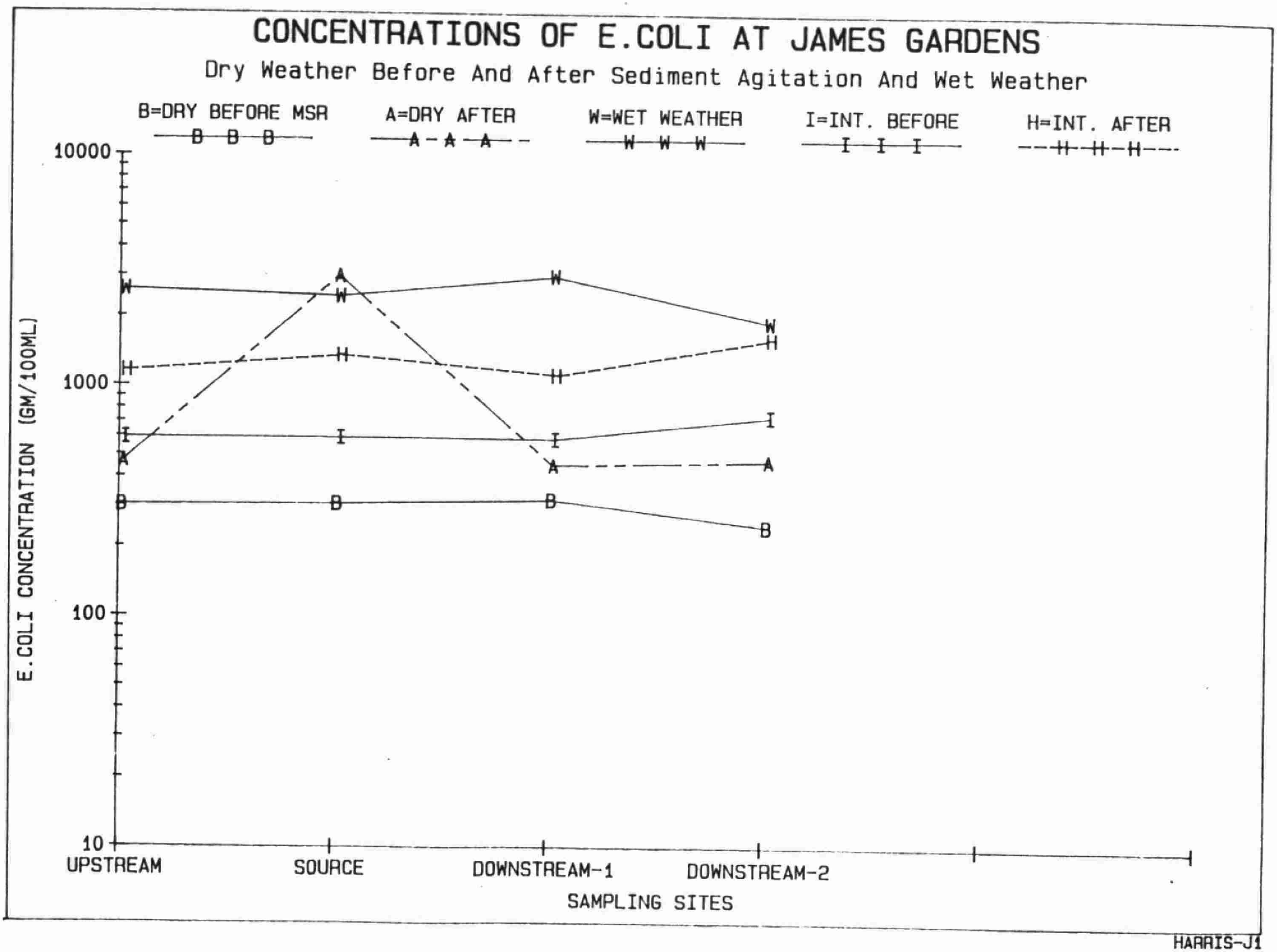
The direct impact of bird fecal matter has little effect in increasing water column FIB levels (except PSA) (Figs. 37-41 and Table 22) due to the high pollution loadings entering from upstream under all weather conditions. The decrease in streptococcus populations at source, however, could be an indication of the increased presence of fecal material (higher FC, lower FS). The increases in some FIB densities at DN1 and sometimes DN2 under different weather conditions, especially PSA, (Fig. 41) is most likely due to resuspension of contaminated sediment from source and the resulting downstream transport. The ability of PSA to survive and even grow under certain environmental conditions (41) may result in better survival or growth in the area of the source site due to the fecal inputs. This could

Figure 37:

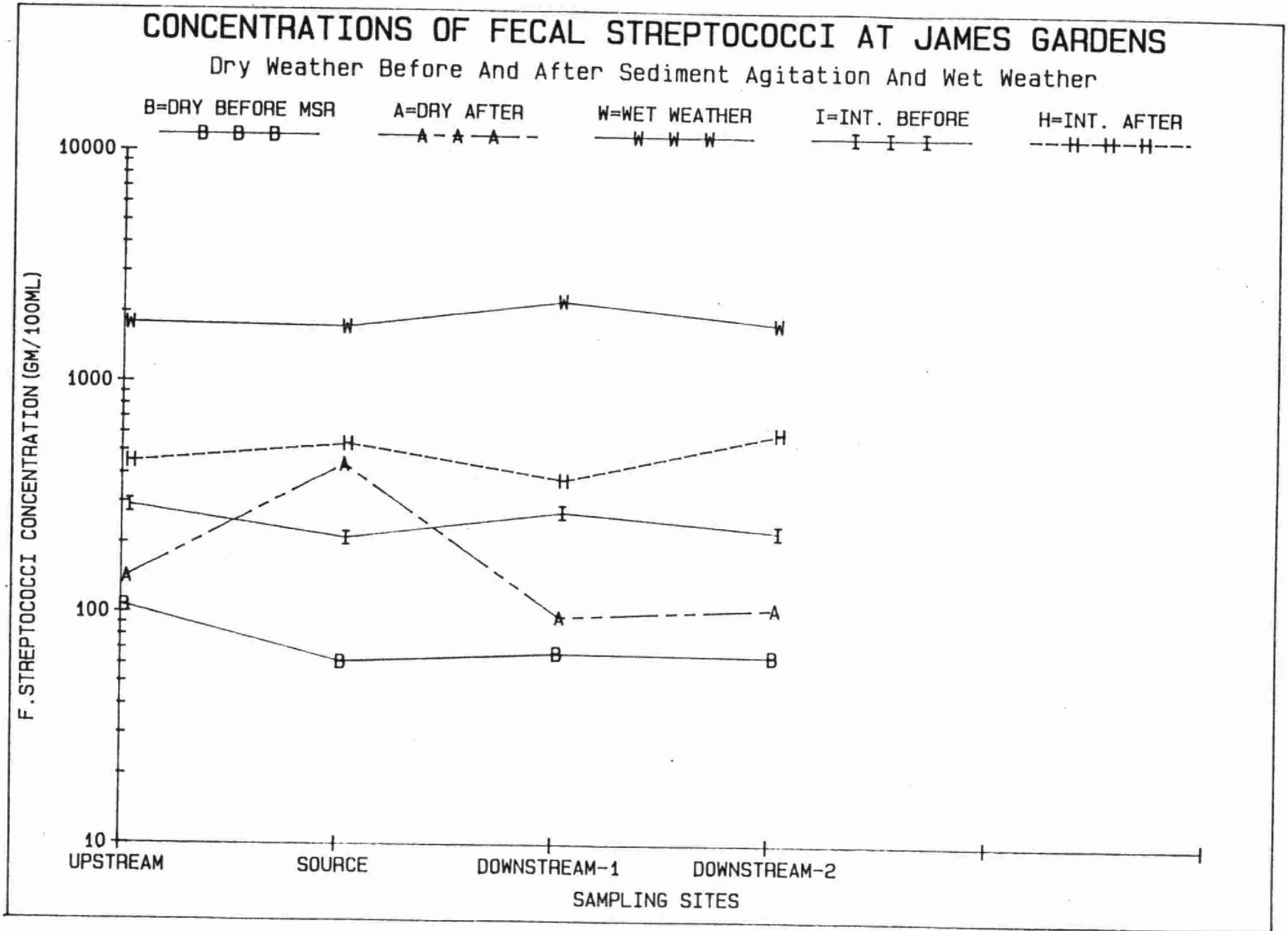


CONCENTRATIONS OF FECAL COLIFORMS AT JAMES GARDENS
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
10000
1000
100
10
F.COLIFORM CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SAMPLING SITES
HARRIS-J2

Figure 38:

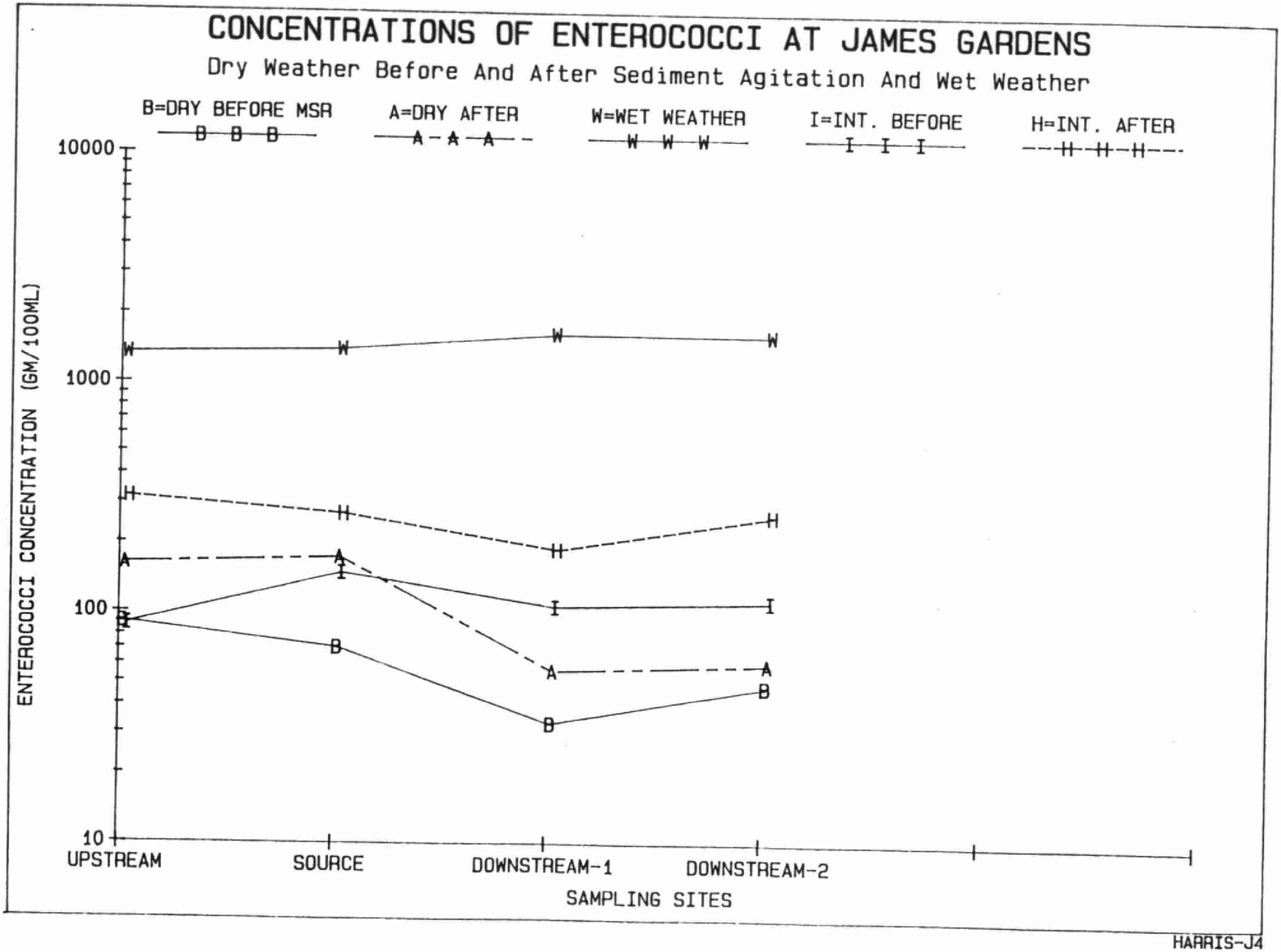

CONCENTRATIONS OF E.COLI AT JAMES GARDENS
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
10000
1000
100
10
E.COLI CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SAMPLING SITES
HARRIS-J1

[redacted]ure[redacted]:

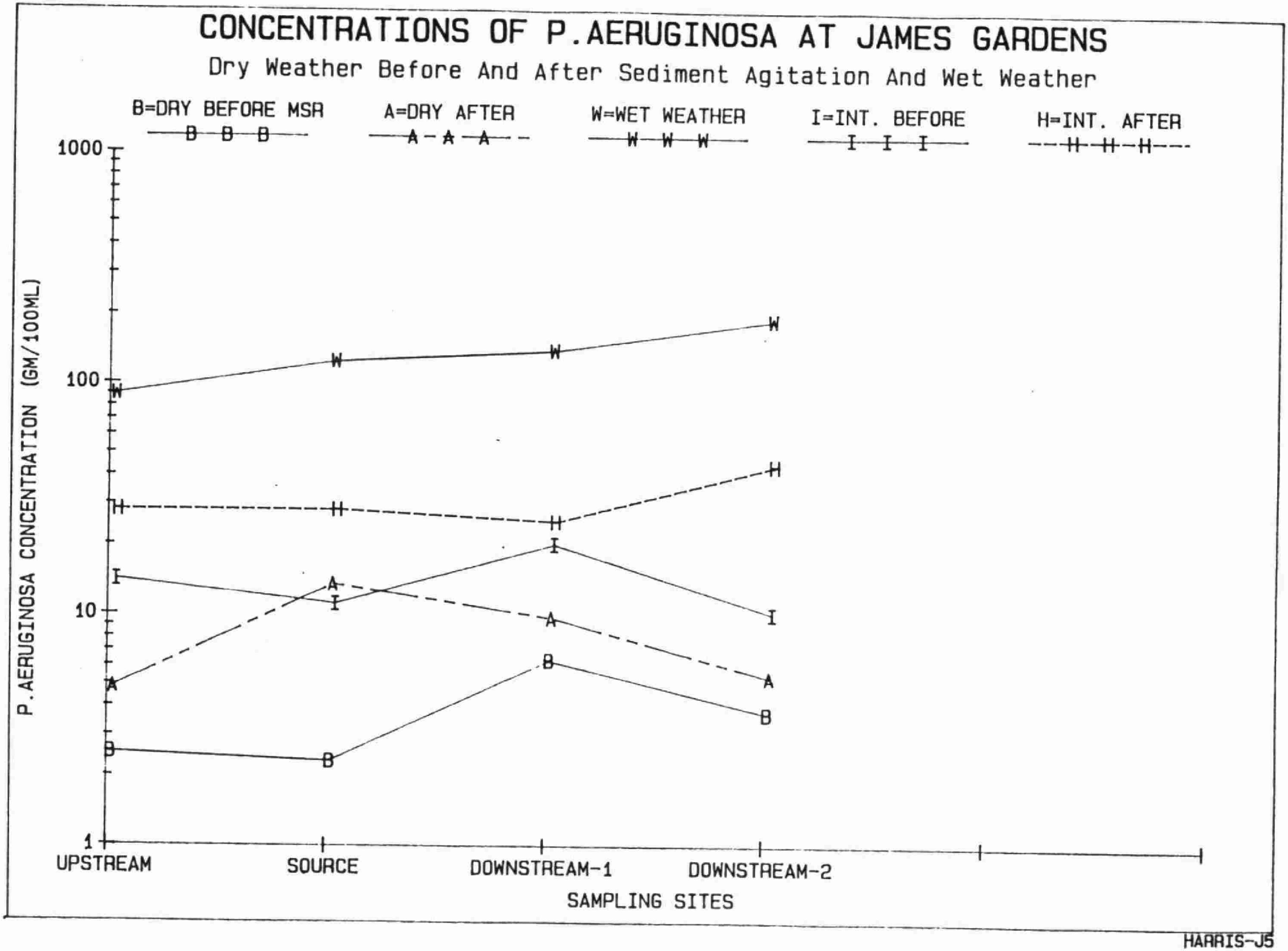


HARRIS-J3

Figure 40.


CONCENTRATIONS OF ENTEROCOCCI AT JAMES GARDENS
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
ENTEROCOCCI CONCENTRATION (GM/100ML)
10000
1000
100
10
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SAMPLING SITES
HARRIS-J4

F[redacted]re [redacted]



cause a somewhat greater effect on the water column as a result of SED resuspension.

The application of MSR during dry weather demonstrated the obvious impact of the bird fecal material at source. The disappearance of this effect during intermediate conditions with some evidence of an increased effect downstream is in keeping with the resuspension and transport of contaminated sediments from source with some redeposition at DN2. It should be noted that although the greatest concentration of birds was constantly observed to be in the source area, they were obviously not restricted to this site and were sometimes observed upstream. Bird activity could thus be partially responsible for the poor water quality observed at UP.

FC/FS

The impact of the fresh fecal material is readily apparent both before and after MSR (Fig. 42 and Table 22) and is maintained downstream even though actual bacterial densities have decreased. Since the source of fecal input is known to be birds, primarily gulls, the FC/FS ratios attained which are as high as 8.4, are further evidence that a ratio higher than 4.0 does not automatically indicate human input.

The location appears to be dominated by upstream inputs during wet weather. The lower FC/FS ratios from source to downstream may be the result of resuspension of older sediments. It would be of interest to observe the changes in relative

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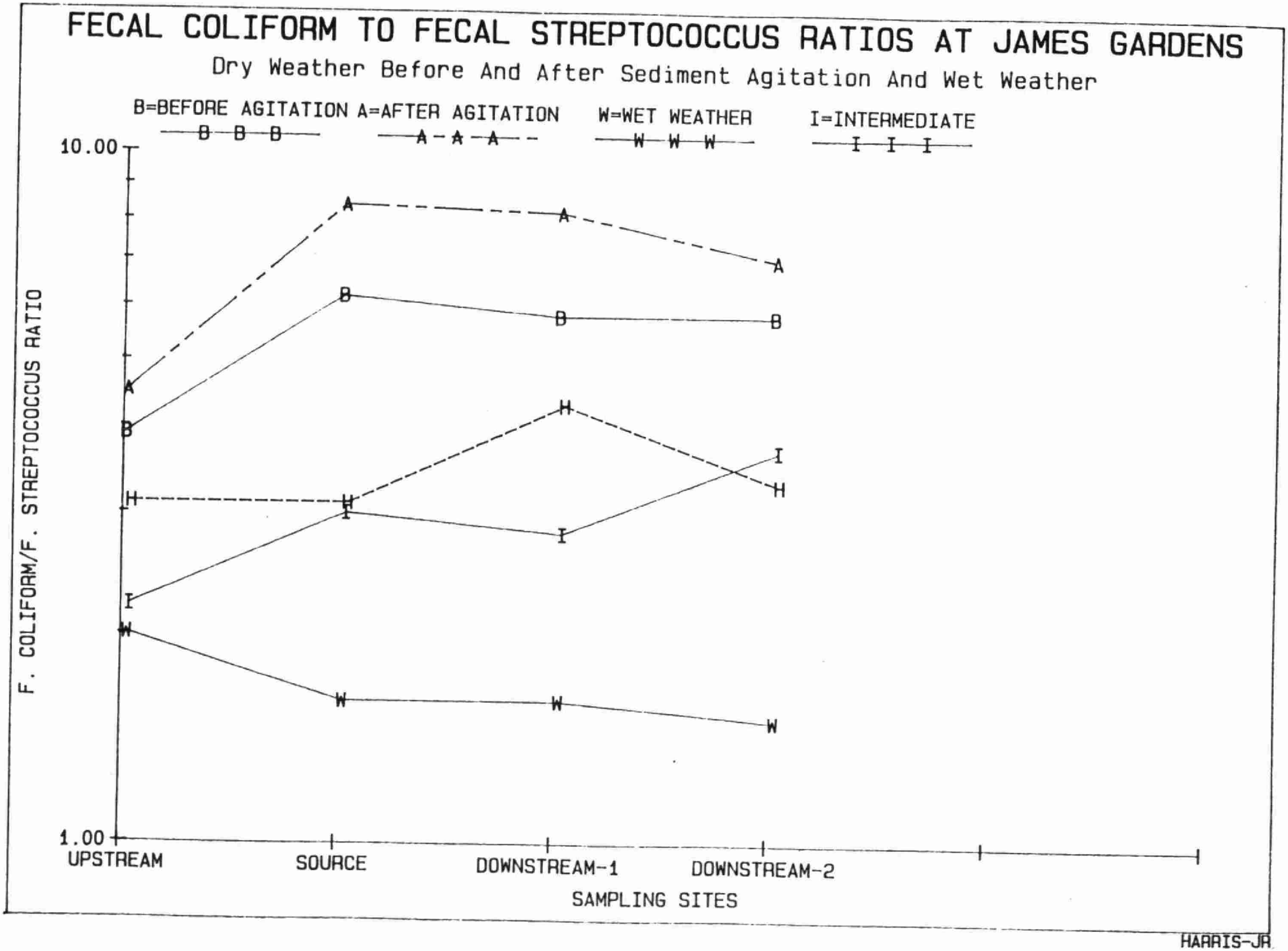


Table 23:

Escherichia Coli to Fecal Coliform Ratios During
Post-Rainfall Period at
James Gardens

Site	Number of Days Following Rainfall				
	0	1	2	3	4
UB	4437/6210 (0.71)	589/645 (0.91)	580/636 (0.91)	195/309 (0.63)	152/168 (0.90)
UA		1152/1394 (0.83)	547/603 (0.91)	419/661 (0.63)	150/150 (1.0)
SB	4038/4569 (0.88)	592/623 (0.95)	277/341 (0.81)	327/406 (0.81)	76/80 (0.95)
SA		1349/1660 (0.81)	5023/6261 (0.80)	2111/2595 (0.81)	1700/2400 (0.71)
DN1B	4698/5599 (0.84)	583/772 (0.76)	348/427 (0.81)	304/363 (0.84)	208/232 (0.90)
DN1A		1113/1627 (0.68)	434/538 (0.81)	463/1019 (0.45)	260/290 (0.90)
DN2B	3147/4495 (0.70)	738/835 (0.88)	281*/313* (0.90)	224/422 (0.53)	124/160 (0.78)
DN2A		1608/1989 (0.81)	548/693 (0.79)	431/759 (0.57)	300/400 (0.75)

$\frac{\text{E.coli}}{\text{F. coliforms}}$ (Ratio) *approximate value

bacterial levels through the initial stages of a storm as there may be an initial increase in FC/FS as the more freshly deposited sediments are resuspended.

The observed FC/FS ratios during intermediate conditions are suggestive of a response to inputs but because of the high levels at UP following MSR, the ratio at source could, at least in part be due to sediment resuspension. MSR also indicates a shift in dry weather source SED deposits to DN1. Further resuspension from DN1 could be impacting on DN2 resulting in the increased water column levels.

Post-Rainfall Bacterial (EC/FC) Quality

The EC/FC ratios during the period representative of wet weather (day 0) (Table 23) are indicative of relatively recent fecal inputs throughout this location with somewhat more recent impacts at source and DN1. This same pattern is evidenced by the EC/FC mean ratios (Table 22).

The drop in water column FC and EC concentration on day 1 (intermediate weather) is most likely the result of a decrease in upstream loadings and increased deposition as opposed to a "wash-out" effect. The sediment densities are definitely elevated. The trend to higher EC/FC at the same time would be due to the decreased impact from older upstream inputs. The decrease in EC/FC, occurring at DN1, cannot be readily explained, but may be related to a continued impact from resuspended sediments from within this location. The tendency for EC/FC ratios to decrease,

after MSR at all sites, also indicates some deposition of older upstream contamination.

The trend from day 2 to day 4 as dry weather conditions are re-established is to decreasing EC and FC levels but higher ratios indicating a return to an impact from fresher inputs (i.e. direct input of bird feces).

The general drop in EC/FC on day 3 appears to be related to a washout effect or temporary increase in non-fecal inputs up-stream while the lower EC/FC and DN2 shows that the direct impacts felt at source and DN1 are reduced due to sedimentation or dilution by the main Humber River by the time they reach this site.

Natural Environmental Phenomena and Bacterial Concentrations

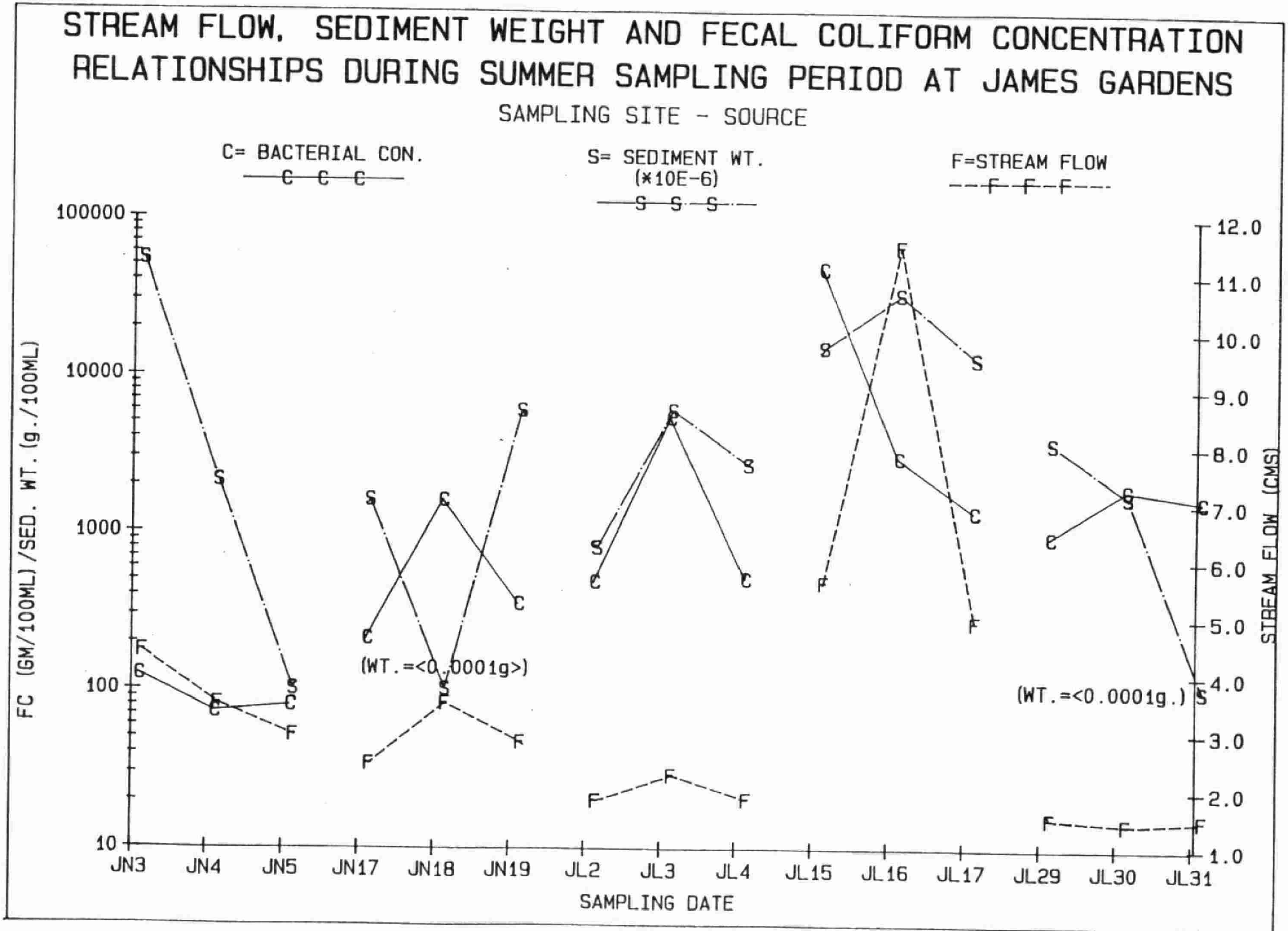
The different stages of effect of storm events on flow, and bacterial and sediment levels noted at other sites are apparent at James Gardens (Figs. 36-44 and Table 22).

The third survey was the only one that caught the peak value of all three parameters while the first is indicative of a return to dry weather conditions.

The temporary drop in SED levels during the second survey could be due to a washout effect occurring upstream; if it were a localized effect prior to the re-introduction of gull feces then bacterial concentrations might also be expected to increase.

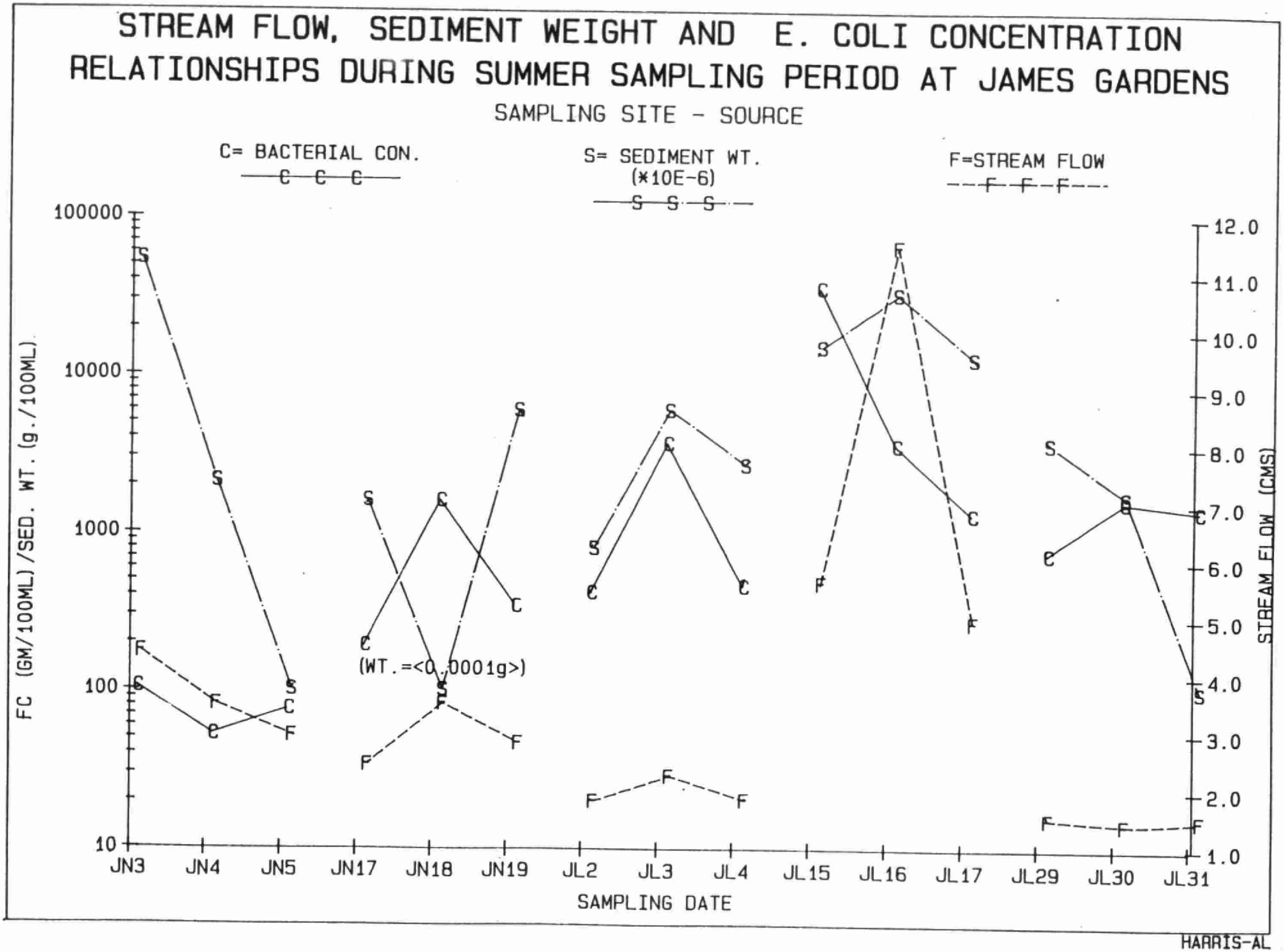
The pattern observed during the fourth survey suggests that the maximum bacterial impact was reached early during the storm

Fi[redacted]e 4



HARRIS-AZ

Figure 44:



STREAM FLOW, SEDIMENT WEIGHT AND E. COLI CONCENTRATION RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT JAMES GARDENS
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT. (*10E-6)
F=STREAM FLOW
FC (GM/100ML)/SED. WT. (g./100ML)
STREAM FLOW (CMS)
100000
10000
1000
100
10
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
(WT.=<0.0001g>)
JN3
JN4
JN5
JN17
JN18
JN19
JL2
JL3
JL4
JL15
JL16
JL17
JL29
JL30
JL31
SAMPLING DATE
HARRIS-AL

event before sampling occurred on the first day. This could have been caused by the severity of the storm.

The changes during the final survey are as difficult to explain at this location as at the others. The flow is relatively constant and yet increases in bacterial concentrations are occurring. Bird inputs might be suspected but the sediment levels are decreasing at the same time and similar effects on bacterial densities were noted at the other lower Humber River locations.

The sediment/sediment regression analyses (Table 24) suggests that S.SED levels are effected by similar factors at all sites. There is some decrease in the correlation coefficients at DN2 which may be due to an increase in impact from a different source, perhaps the bird feces or resuspension of sediments within the study location. This inter-mixing of factors with source inputs being a key are also suggested by the SED/flow regression analyses.

It is interesting that the SED/bacteria comparisons only show significant correlations at DN2. This indicates that factors effecting the bacterial levels and S.SED do not overlap until DN2, again suggesting inputs occurring within location (i.e. birds) as being the link.

The EC, FC regression analyses (Table 25) demonstrate a high relationship between bacterial concentrations at all sites. The only indication of a specific impact at source is a slight

Table 24:

Correlation Coefficients of Suspended Sediment Weights
(Before Sediment Agitation) with Fecal Coliform, Escherichia coli
Counts and Flow Rate at
James Gardens

Sediment Weight	Sediment Weight			
	Upstream	Source	Downstream I	Downstream II
Upstream	+ 1.00	+ 0.93	+ 0.93	+ 0.75
Source		+ 1.00	+ 0.97	+ 0.84
Downstream I			+ 1.00	+ 0.86
Downstream II				+ 1.00
Fecal coliforms				
Upstream	+ 0.45	+ 0.40	+ 0.43	+ 0.72
Source	+ 0.49	+ 0.43	+ 0.46	+ 0.71
Downstream I	+ 0.47	+ 0.40	+ 0.46	+ 0.72
Downstream II	+ 0.52	+ 0.42	+ 0.46	+ 0.64
E. coli				
Upstream	+ 0.45	+ 0.41	+ 0.44	+ 0.72
Source	+ 0.53	+ 0.47	+ 0.50	+ 0.72
Downstream I	+ 0.48	+ 0.41	+ 0.48	+ 0.73
Downstream II	+ 0.53	+ 0.45	+ 0.49	+ 0.69
Flow rate	+ 0.88	+ 0.92	+ 0.92	+ 0.75

Table 25:

Correlation Coefficients of Fecal Coliform, Escherichia coli Counts and Flow Rate at James Gardens

	Fecal Coliforms			
E. coli	Upstream	Source	Downstream I	Downstream II
Upstream	+0.99	+0.94	+0.97	+0.91
Source	+0.96	+1.00	+0.97	+0.95
Downstream I	+0.98	+0.97	+0.99	+0.95
Downstream II	+0.94	+0.93	+0.95	+0.98
Fecal coliforms				
Upstream	+1.00	+0.97	+0.98	+0.93
Source		+1.00	+0.77	+0.95
Downstream I			+1.00	+0.95
Downstream II				+1.00
Flow rate	+0.27	+0.25	+0.26	+0.25
E. coli	E. coli			
Upstream	+1.00	+0.94	+0.97	+0.94
Source		+1.00	+0.97	+0.94
Downstream I			+1.00	+0.94
Downstream II				+1.00
Flow rate	+0.30	+0.30	+0.30	+0.33

decrease in correlation. Basically upstream and localized effects appear to be inter-mixing throughout the location.

The fact that flow does not correlate to EC and FC levels while doing so with S.SED indicates that resuspension of sediment at this location and sediments transported in from upstream are not the major impact on bacterial concentrations.

Streptococcus Populations

The proportionally higher populations of S. faecalis var liquefaciens in comparison to S. faecium at all sites (Table 26), especially in the sediment, is in good agreement with the population distribution found in gull feces (P. Seyfried, E. Harris and M. Young, 1986 unpublished data).

The high proportional levels of S. durans present indicate impacts from additional upstream sources other than gulls, possibly human and additional animal inputs (e.g. dogs).

The shift to S. faecium var faecium during wet weather indicates a possible increase in human inputs from upstream inputs.

Bacterial Survival

E. coli demonstrated extremely rapid die-off rates during summer conditions (Fig. 45, Table 27) with a decrease of over three orders of magnitude in the first 24 hrs. of exposure. Considering the high input of fecal material the extreme unsuitability of this area to E. coli is surprising. Perhaps

Table 26:

Fecal Streptococcus Populations at James Gardens Under Wet and Dry Weather Conditions

Site and cond.		Total Isolates	S.faecalis faecalis	S.faecalis liquefaciens	S.faecalis zymogenes	S.faecium	S. faecium casseliflavus	S.durans	S.bovis	S.avium	Fecal Strep.	Non-fecal streptococci	Aerococcus
UPSTRM	Dry Before	16	3(18.8)	3(18.8)	-	1(6.3)	1(6.3)	8(50.0)	-	-	-	-	-
	Dry After	20	3(15.0)	7(35.0)	1(5.0)	2(10.0)	2(10.0)	5(25.0)	-	-	-	-	-
	Wet	34	4(11.8)	5(14.7)	-	9(26.5)	7(20.6)	8(23.5)	-	-	1(2.9)	-	-
SOURCE	Dry Before	19	-	4(21.1)	-	3(15.8)	4(21.1)	8(42.1)	-	-	-	-	-
	Dry After	14	2(14.3)	4(28.6)	-	3(21.4)	2(14.3)	3(21.4)	-	-	-	-	-
	Wet	38	4(10.5)	7(18.4)	-	8(21.1)	9(23.4)	6(15.8)	1(2.6)	2(5.3)	1(2.9)	-	-
DOWNSTRM	Dry Before	20	1(5.0)	7(35.0)	-	5(25.0)	4(20.0)	3(15.0)	-	-	-	-	-
	Dry After	15	1(6.7)	9(60.0)	1(6.7)	-	-	4(26.7)	-	-	-	-	-
	Wet	33	3(9.1)	6(18.2)	-	8(24.2)	7(21.2)	7(21.2)	-	1(3.0)	1(3.0)	-	-
EFFLUENT	Dry Before												
	Dry After												
	Wet												
Total column		209	21	47	2	39	36	57	1	3	1		

Percentages in Parenthesis ( )

Figure 45:

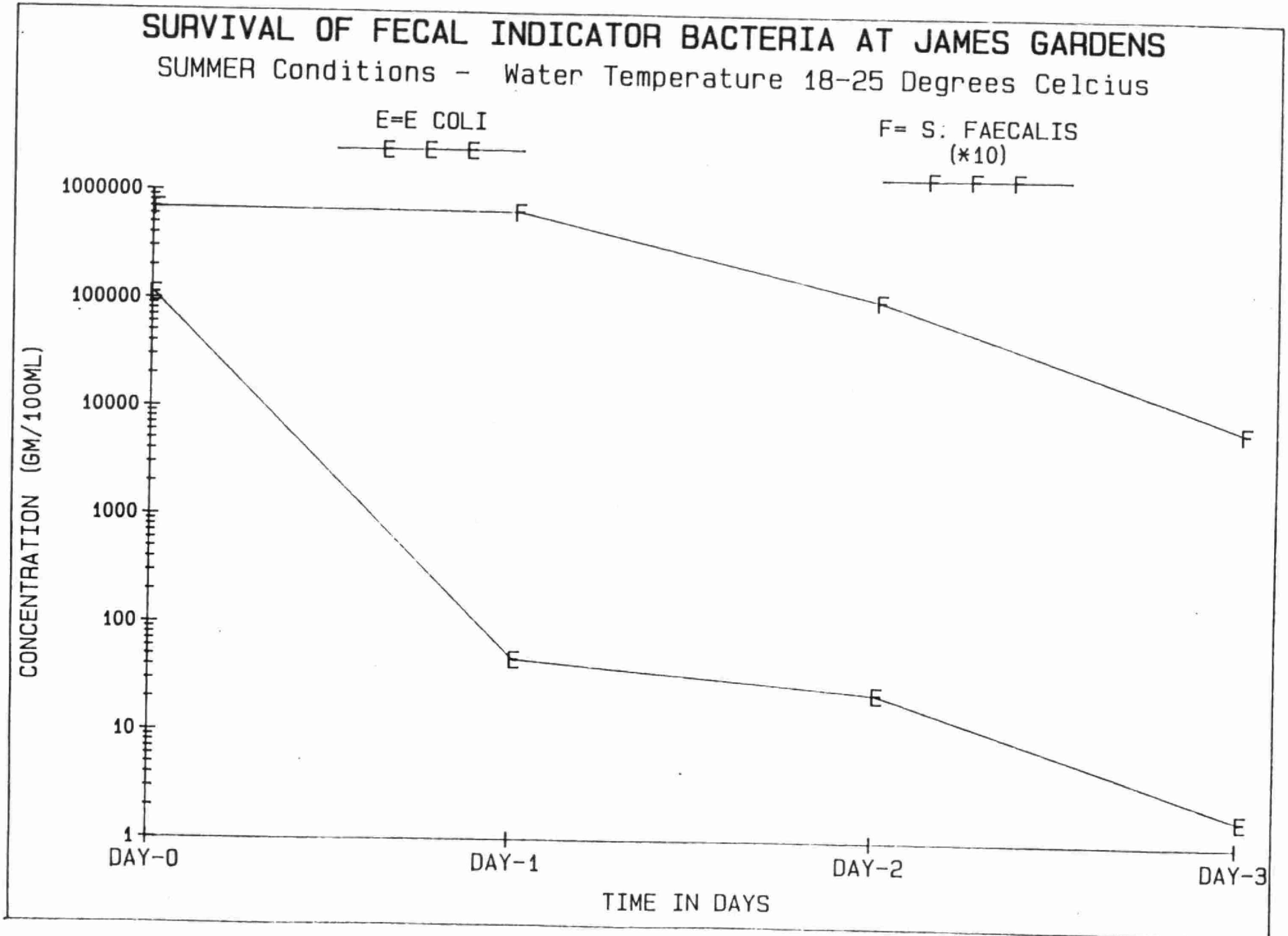


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Table 27:

Percent die-off of fecal indicator bacteria at James Gardens (Water fowl access site) during summer weather conditions (Average water temperature 20 $\pm$ 3°C)

Bacterial Culture	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli (50 ml chamber	1.1×10^5	46	23	1.7
Strep. faecalis (50 ml chamber	6.8×10^6	6.6×10^6	1.04×10^6	6.8×10^4
Strep. faecium (50 ml chamber)	2.9×10^5	chamber lost	-	-

Table 28:

Percent die-off of fecal indicator bacteria at James Gardens (Water fowl access site) during winter weather conditions (Average water temperature 8.5 $\pm$ 5°C)

Bacterial Culture (50 ml chamber)	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli	1.6×10^5	2.9×10^4	2.5×10^4	2.5×10^3

water quality related to upstream inputs is the cause. The much decreased E. coli die-off rates from 24 to 72 hrs. exposure are probably due to the increased tolerance to environmental conditions of the bacteria remaining after the first 24 hours.

It is readily apparent that S. faecalis survives very well at this site (Fig. 45, Table 27) and in fact showed little decline over the first 24 hrs. followed by a decline of two orders of magnitude over the following 48 hrs. Under conditions like these streptococci introduced at this site would be recovered much further downstream than the E. coli.

During winter conditions recoveries could only be obtained for E. coli (Fig. 46, Table 28). These demonstrated that the reduction, in metabolic activity brought on by lower temperatures effectively increased survival by about three orders of magnitude over the three day exposure. This change was primarily due to the decreased die-off during the first 24 hrs. which further demonstrates the increased ability to survive at colder temperatures (all other factors being approximately the same).

The net effect would be that pollution input under colder temperatures would be impacting on much larger distances of the river system. This type of effect is of concern because it may also enhance the survival of pathogenic organisms.

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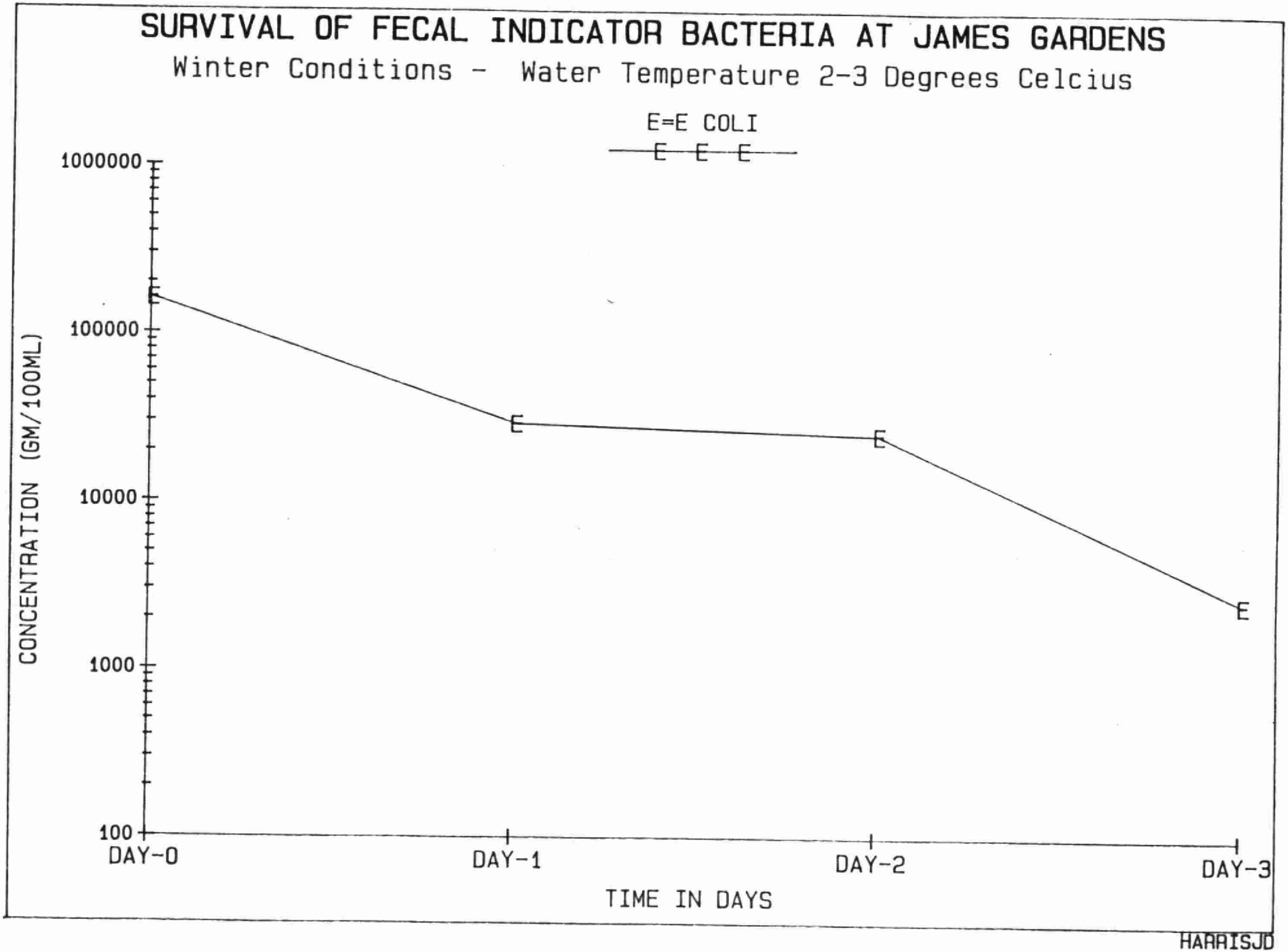

Teston Road (Cattle Access Site)

Sediment Resuspension

Sediment

The direct input of feces by cattle can be readily observed by the application of MSR in much the same way as the impact of gulls at James Gardens (Fig. 47 and Table 29). The major deposits under both dry and intermediate conditions are observed at source. The main difference between dry and intermediate conditions, following MSR, is the obvious reduction of SED deposits at DN2 during intermediate weather.

The effect of sediment resuspension and transport is evident in the water column at source, DN1 and DN2 during intermediate weather and possibly DN2 during dry weather. Sediment deposition may be occurring even further downstream, under dry weather conditions but this cannot be determined since there was no sampling done below DN2.

The apparent lack of washout of deposits at source and DN1 during wet weather may simply be due to ongoing inputs from land runoff carrying accumulations of cow feces. This type of ongoing direct input coupled with continued resuspension and transport may be responsible for the increased water column levels, before MSR, during intermediate conditions from source to DN1 as well as UP to source.

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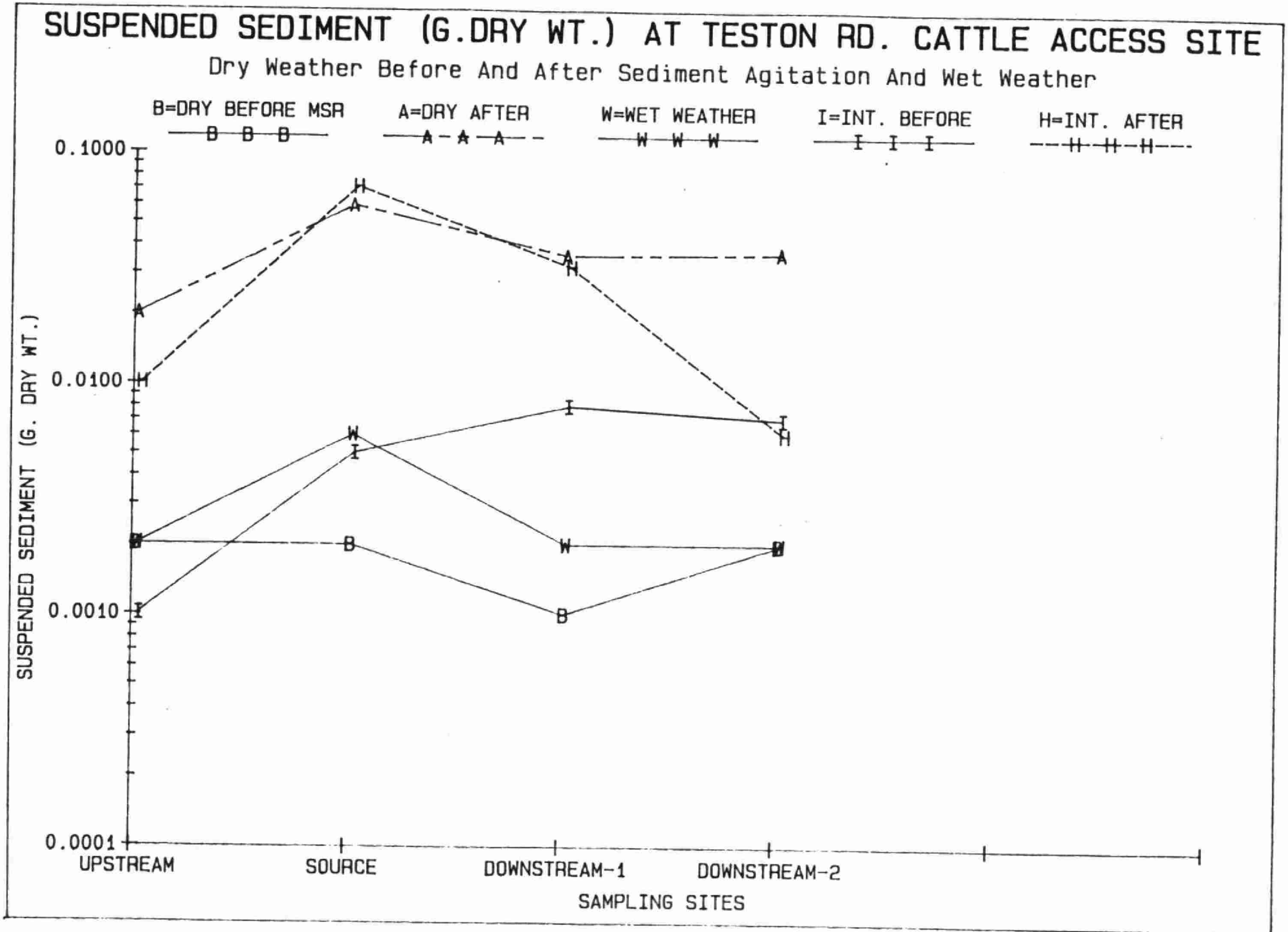


HARRIS-TS

Table 29:

Geometric mean concentrations of Fecal Indicator Bacteria, E. coli to Fecal Coliform ratios, Fecal Coliform to Fecal Streptococci Ratios and Suspended Sediment Weights During Dry and Intermediate Weather (Before and After Sediment Agitation) and Wet Weather at Teston Road

Sampling site and weather cond.		Fecal coliforms	E. coli	Fecal Streptococci	Enterococci	P. aeruginosa	EC/FC Ratio	FC/FS Ratio	Suspended sediment (grams/100mls)
		(per 100 ml water sample)							
upstream	B	144	138	181	140	1.2	0.96	0.8	0.002
dry	A	164	153	185	150	2.2	0.93	0.9	0.020
Int.	B	645	589	288	137	1.0	0.91	2.2	0.001
	A	312	299	398	266	1.0	0.96	0.8	0.010
wet		359	356	464	289	2.9	0.99	0.8	0.002
source	B	1,944	1,874	358	355	1.01	0.96	5.4	0.002
dry	A	3,080	2,855	421	479	4.3	0.93	7.3	0.059
Int.	B	2,474	2,428	2,317	4,569	1.7	0.98	1.1	0.005
	A	8,695	8,325	2,784	2,324	1.4	0.96	3.1	0.071
wet		6,627	6,358	1,090	2,404	5.8	0.96	6.1	0.006
downstream I									
dry	B	2,213	2,065	227	316	1.3	0.93	9.7	0.001
	A	3,113	2,997	325	307	3.1	0.96	9.6	0.036
Int.	B	13,587	13,394	3,320	2,929	1.4	0.96	4.1	0.008
	A	11,916	11,198	4,441	2,062	2.0	0.94	2.7	0.032
wet		5,550	5,417	859	1,400	5.0	0.98	6.5	0.002
downstream II									
dry	B	2,538	2,466	328	445	1.8	0.97	7.7	0.002
	A	3,262	3,178	456	527	4.6	0.97	7.2	0.037
Int.	B	10,392	10,129	3,709	3,600	1.4	0.97	2.8	0.007
	A	13,278	12,645	5,163	3,926	1.4	0.95	2.6	0.006
wet		6,916	6,661	1,422	1,545	3.8	0.96	4.9	0.002

Bacteria

The bacterial contamination caused by the presence of cattle at this location is apparent, both before and after MSR and under all weather conditions (Figs. 48-52 and Table 29). The most dramatic response is obtained from FC (Fig. 48) and EC (Fig. 49) levels while the lowest effect is from PSA (Fig. 52).

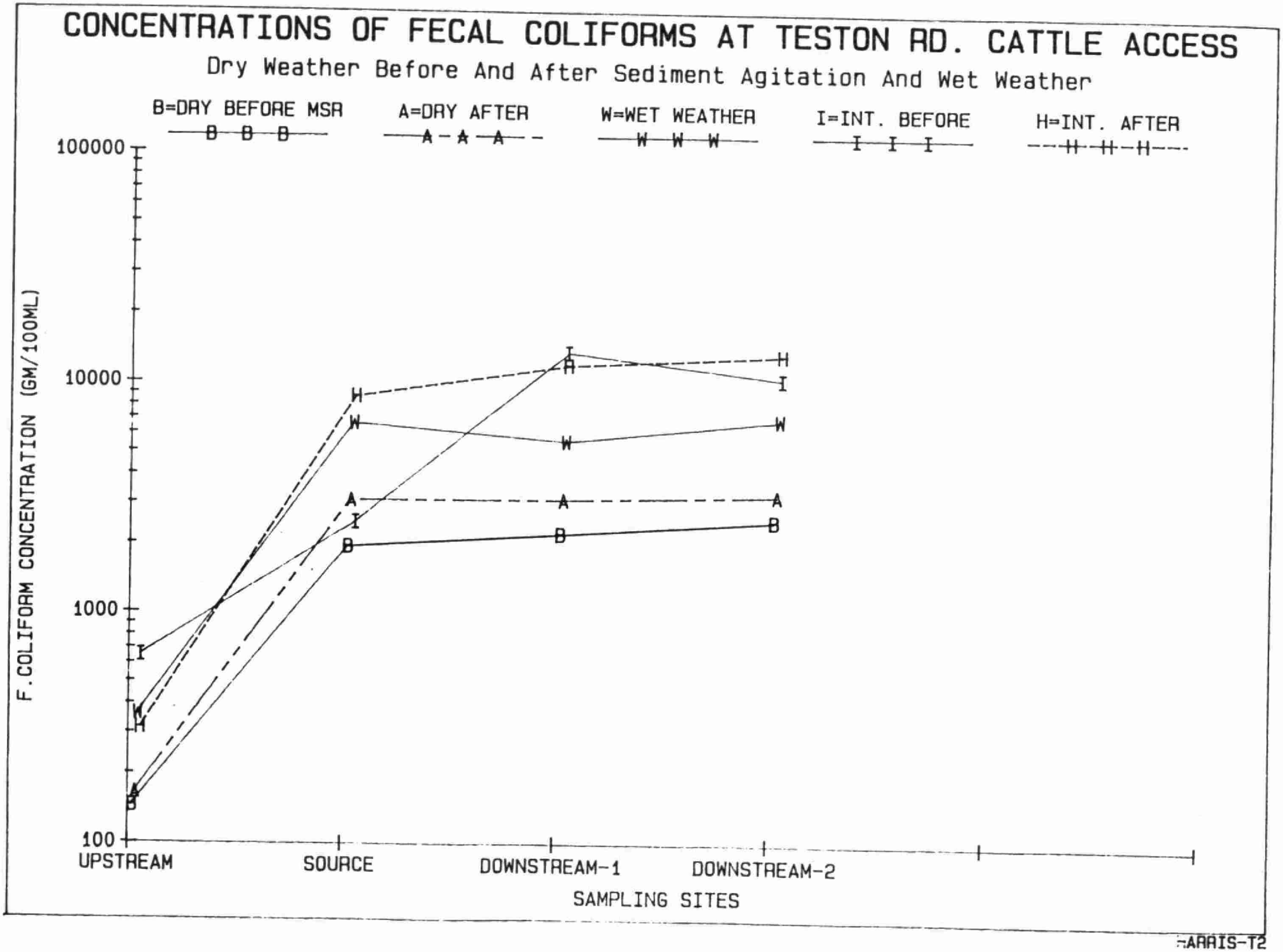
PSA was not recovered from cow feces during the U. of T. fecal study (P. Seyfried, E. Harris and M. Young, 1986, unpublished data) and although this may not be true of all cows, the gradual increase in PSA during dry weather from source to DN2 and the relatively large effect of MSR in comparison to the other FIB are more suggestive of regrowth in the enriched sediments. This could effect water quality as a result of ongoing resuspension.

The minimal or negligible effect of MSR in most cases is probably due to continued SED resuspension at this location. if high flows are not responsible for resuspension of bed sediments, then the action of the cattle in the river will be.

The decreased proportional response of FC and EC at source compared to downstream levels during intermediate conditions is difficult to understand since sediment deposition still appears to be ongoing at this site. It may be that source is effected by the lower upstream sediment and water column (Figs. 50 and 51) bacterial levels.

The drop exhibited in streptococcal levels between source and DN1 which does not occur for FC and EC is probably due to the

Figure 48:



CONCENTRATIONS OF FECAL COLIFORMS AT TESTON RD. CATTLE ACCESS
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
100000
10000
1000
100
F.COLIFORM CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SAMPLING SITES
ARRIS-T2

F[redacted]e [redacted]

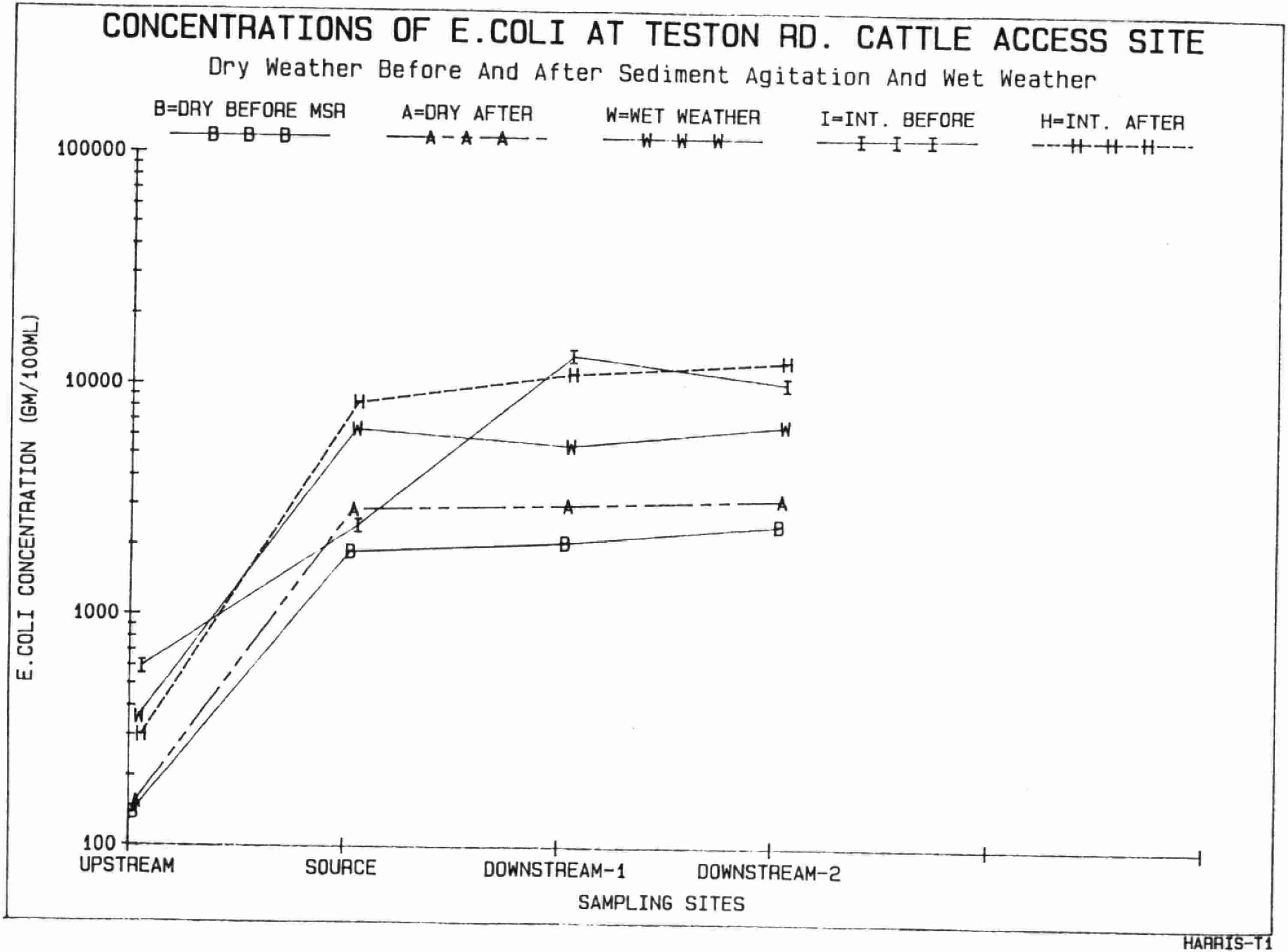
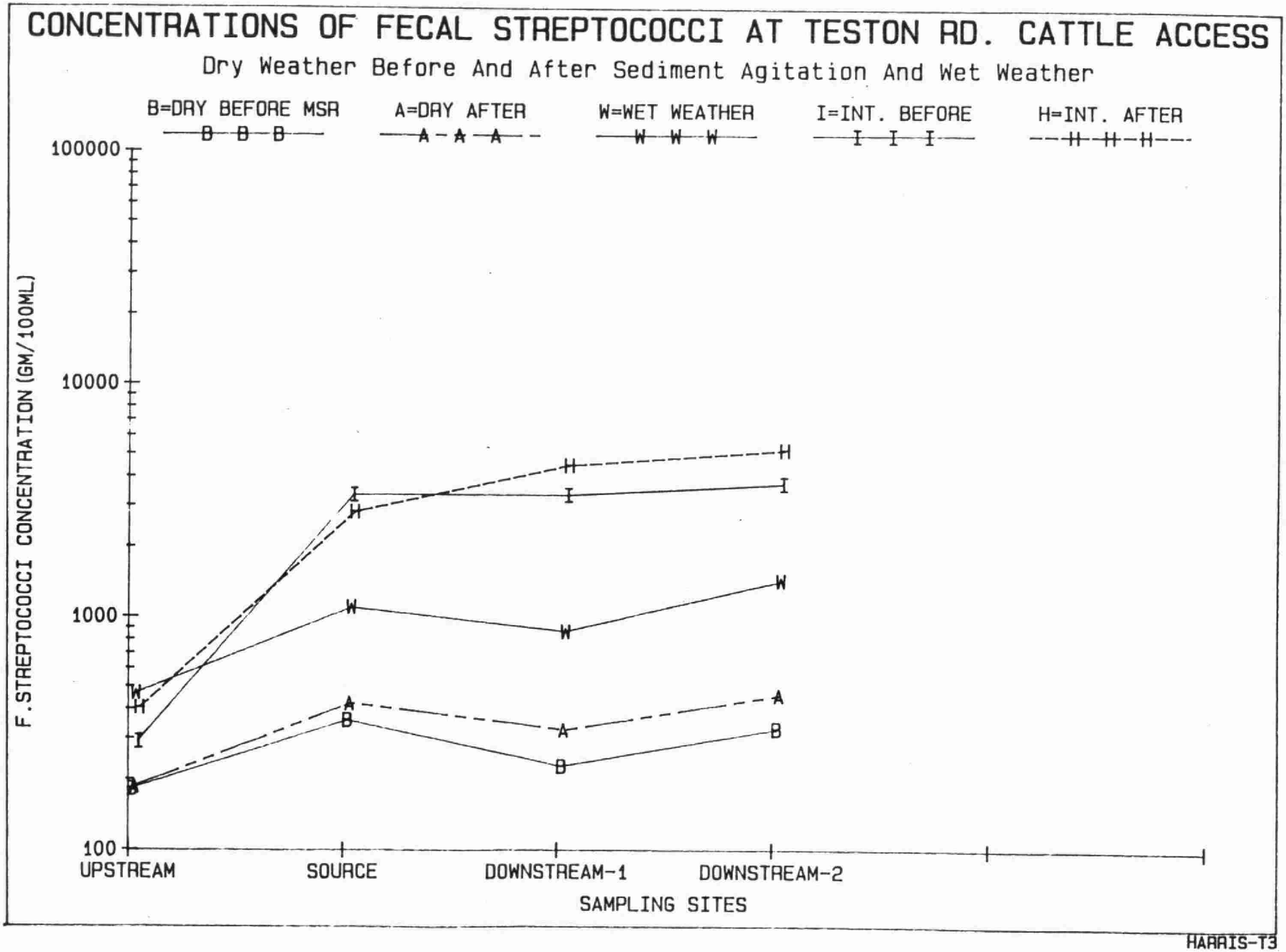


Figure 50:



CONCENTRATIONS OF FECAL STREPTOCOCCI AT TESTON RD. CATTLE ACCESS
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
100000
10000
1000
100
F.STREPTOCOCCI CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SAMPLING SITES
HARRIS-T3

Fi[redacted]e [redacted]:

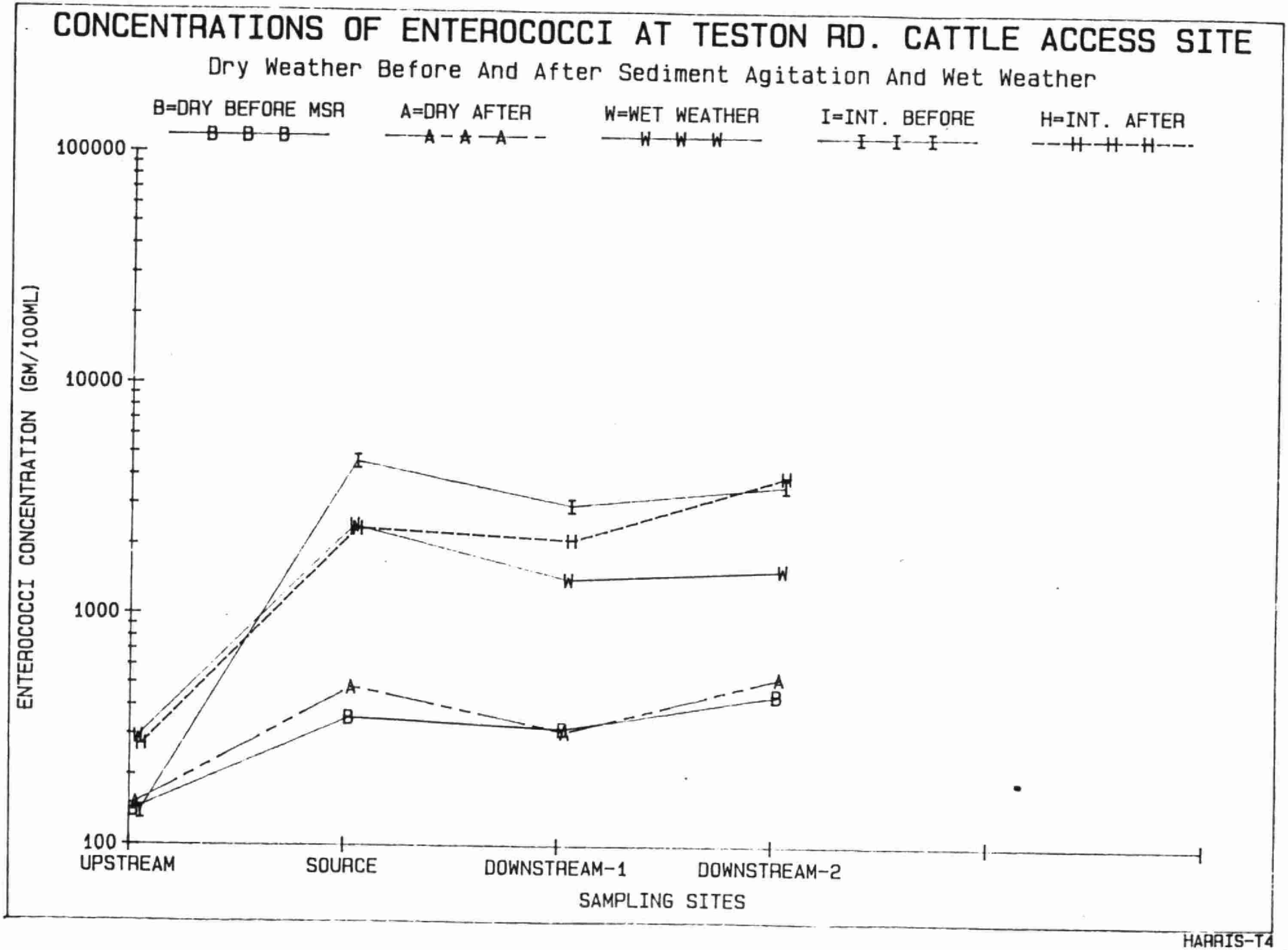
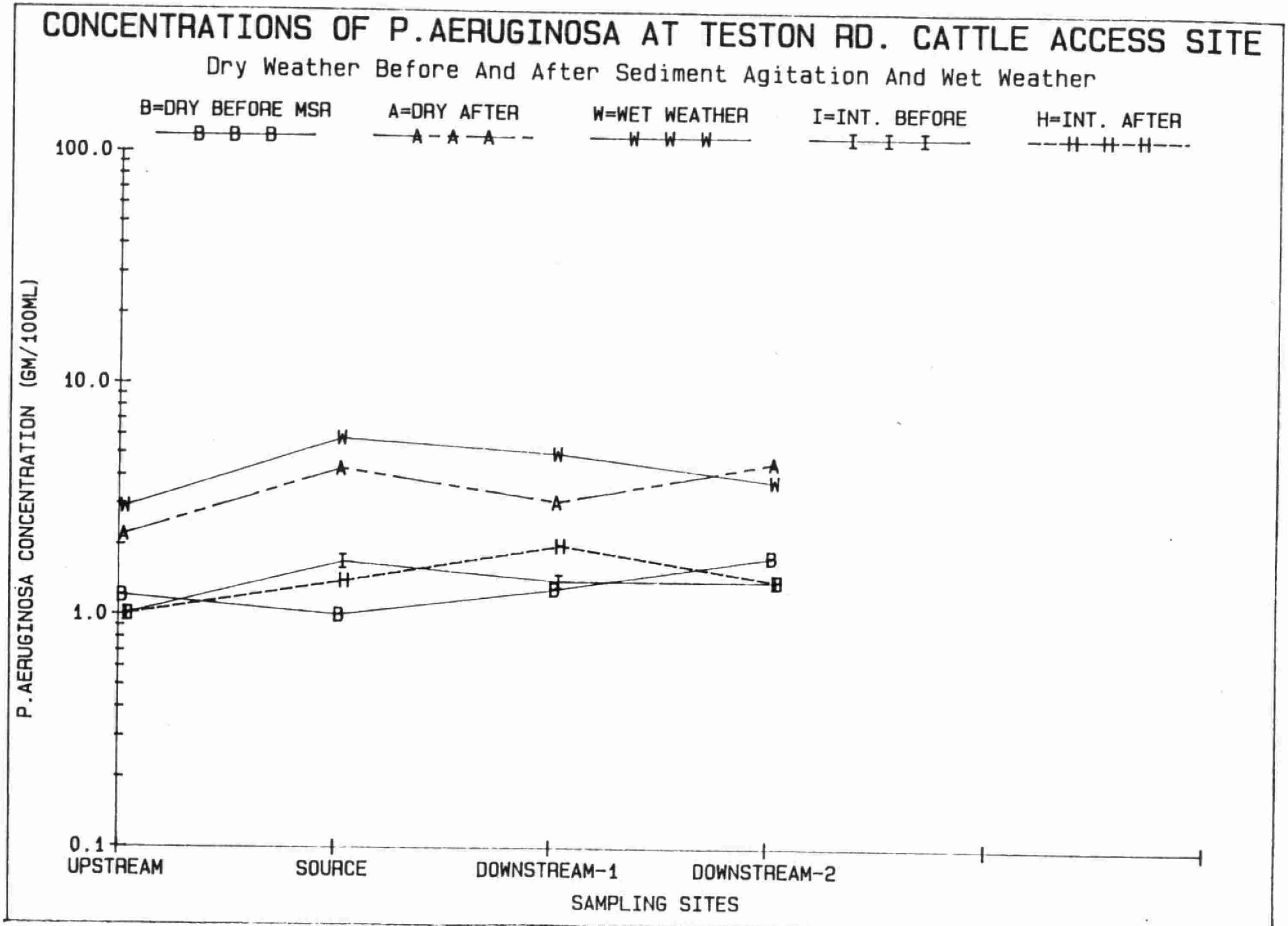


Figure 52:



HARRIS-T5

presence of bacteria such as S. bovis in cow feces that have extremely poor environmental survival abilities (43).

The observation that bacterial contamination is greater during intermediate conditions than wet or dry could be caused by continued inputs from the shore, while flows decrease following a storm.

Another major factor contributing to the impact of the cattle on this location is the relatively small size of the Humber River (east branch) and the correspondingly low flows. This will reduce any dilution effect on fecal material deposited in the river.

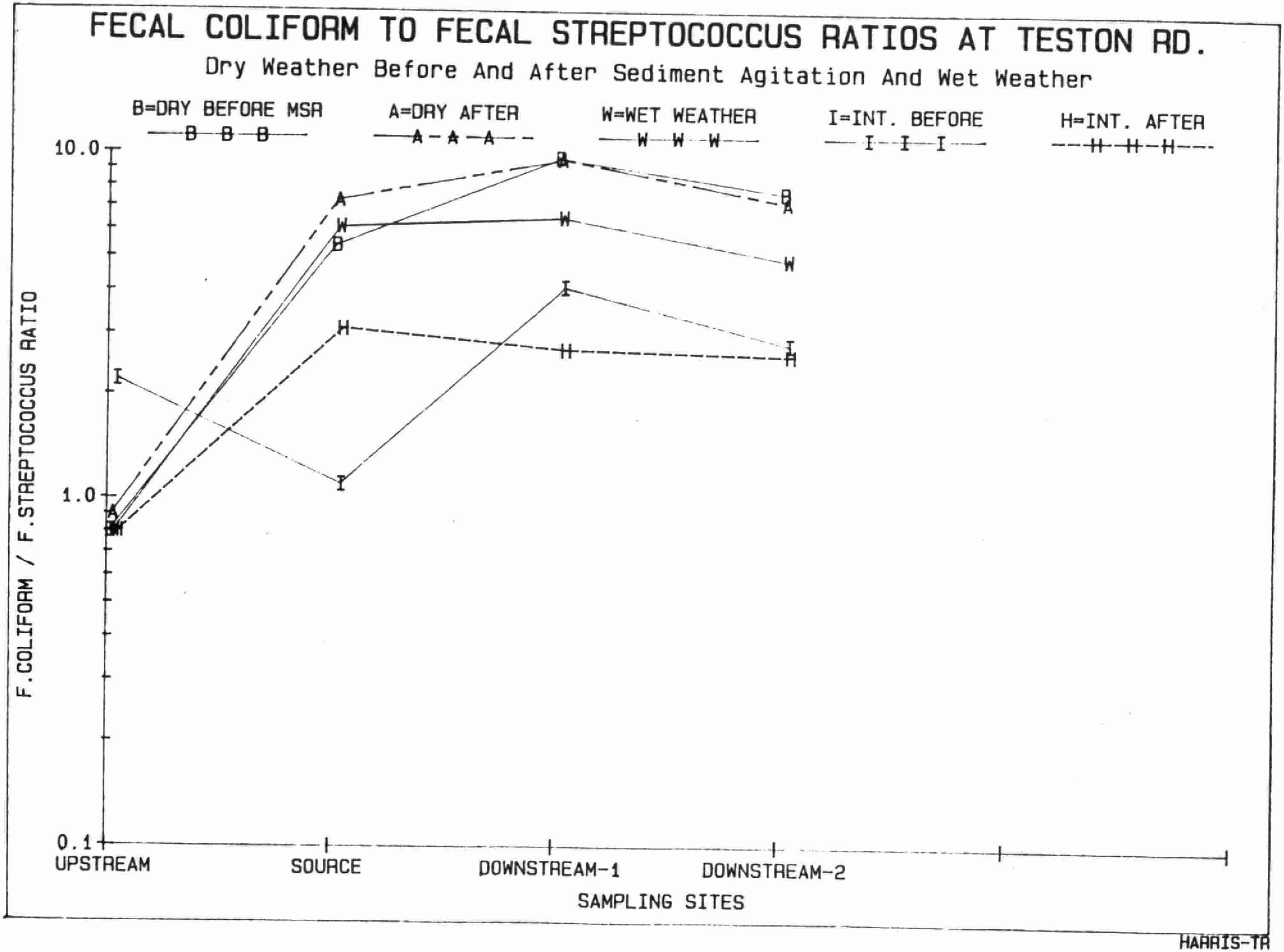
FC/FS

The FC/FS (Fig. 53 and Table 29) ratios show the effects of fecal inputs under both wet and dry conditions at source and downstream. The slightly lower ratios at DN2 during wet may be from the impact of resuspended sediments or land runoff containing older or less fecal contamination.

The slight rise in FC/FS between source and DN1 during dry weather is probably due to the rapid die-off of streptococci such as S. bovis. The ratios present also indicate the invalidity of using an FC/FS ratio greater than 4 of the indicating human input.

The effect of wet weather on this area is evident during intermediate conditions as seen by the high FIB levels. However, the FC/FS ratios tend to be lower during intermediate weather

Figure 53:


FECAL COLIFORM TO FECAL STREPTOCOCCUS RATIOS AT TESTON RD.
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
10.0
1.0
0.1
F.COLIFORM / F.STREPTOCOCCUS RATIO
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
SAMPLING SITES
HARRIS-TR

(except at UP before MSR). It may be that streptococci from older fecal deposits and from plant sources are being washed into the river from continued overland runoff (see Summary).

Post-Rainfall Bacterial (EC/FC) Quality

The most striking observation at this location, following rainfall, is that both the EC/FC values (Table 30) and their ratios based on the mean densities (Table 39) are indicative of recent fecal input at all sites under all conditions examined regardless of actual FIB concentrations observed. This is the most dramatic evidence of fecal input of all the sites studied and is probably related to the magnitude of the input in comparison to the size of the river. Another factor contributing is the ongoing fecal pollution inputs upstream, which although lower, are "recent" in nature. Thus the cattle impact just builds upon an already existing smaller upstream input. Further examination of the area upstream of the study location would be necessary to determine the source of upstream pollution.

Natural Environmental Phenomena and Bacterial Concentrations

There was very little fluctuation noted in flow at this location (Figs. 54A and 54B) and only one period of increased flow was observed. This was during the second survey and followed a rainfall taking place on June 22, 1985 (Fig. 55). The fact that flow was still up on June 24, may be from accumulative

Table 30:

Escherichia Coli to Fecal Coliform Ratios during Post-Rainfall Period at Teston Road

Site	Number of Days Following Rainfall 0	1	2	3	4
UB	2300/2300 (1.0)	217/221 (0.98)	191/199 (0.96	100/112 (.89)	151/159 (0.95)
UA		152/172 (0.9)	225/234 (0.96)	96/96 (1.0)	176/182 (0.97)
SB	23000/25000 (0.92)	3827/3989 (0.96)	2110/2129 (0.99)	380/430 (.88)	2061/2095 (0.98)
SA		4648/4761 (0.98)	4789/4947 (0.97)	680/770 (.88)	2986/3290 (0.91)
DN1B	22000/24000 (0.92)	3183/3234 (0.98)	4956/5013 (0.99)	1060/1060 (1.0)	2444/2733 (0.90)
DN1A		3716/3894 (0.95)	4925/5081 (0.97)	1380/1380 (1.0)	3790/3917 (0.97)
DN2B	25000/29000 (0.86)	3652/3712 (0.98)	3960/4039 (0.98)	800/830 (0.96)	3878/4034 (0.96)
DN2A		2855/2921 (0.98)	5029/5153 (0.98)	1440/1500 (0.96)	4474/4651 (0.96)

$\frac{\text{E.coli}}{\text{F. coliforms}}$ (Ratio) *approximate value

[redacted] F[redacted]re [redacted]A: [redacted]

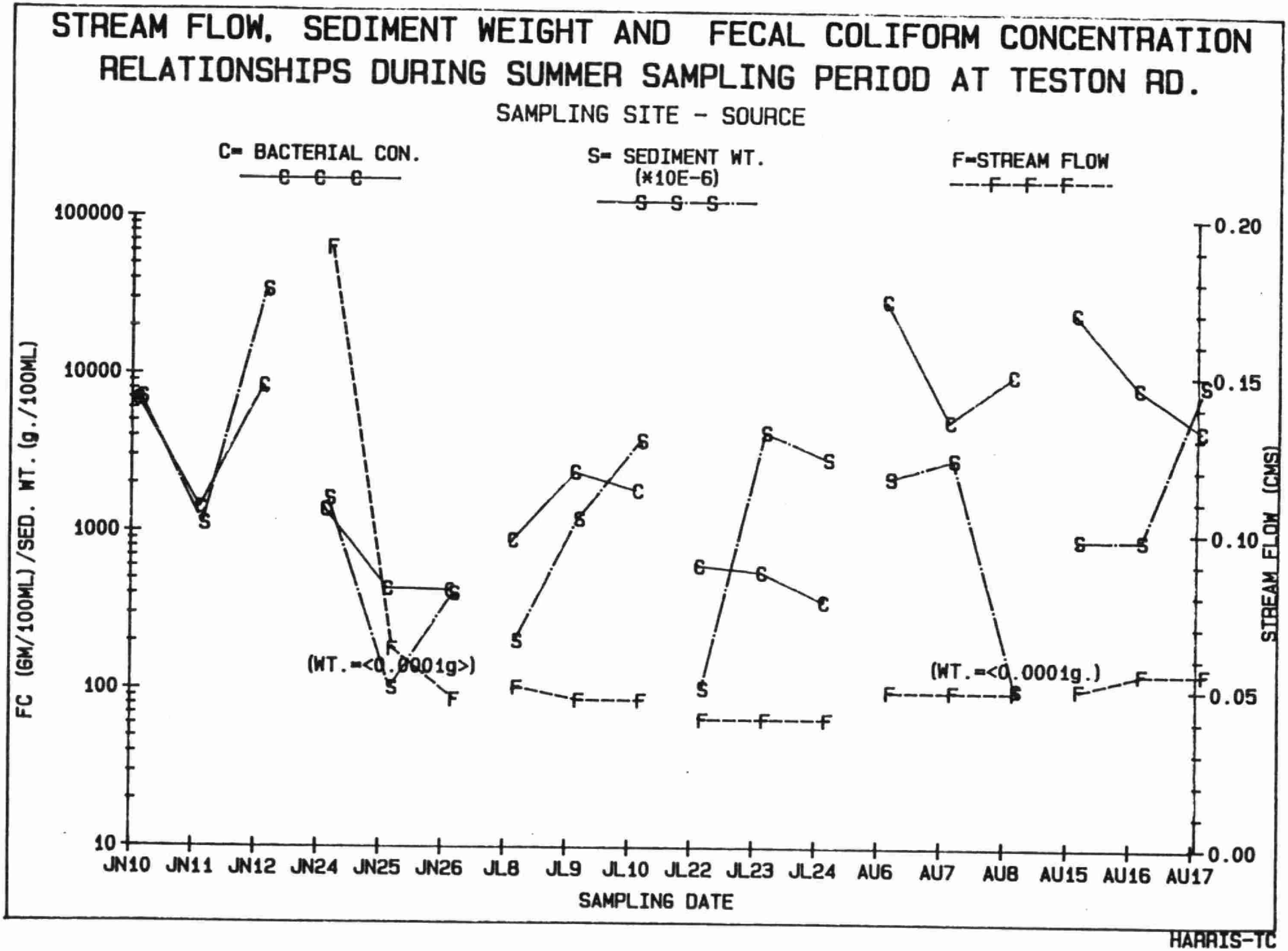


Figure 54B:

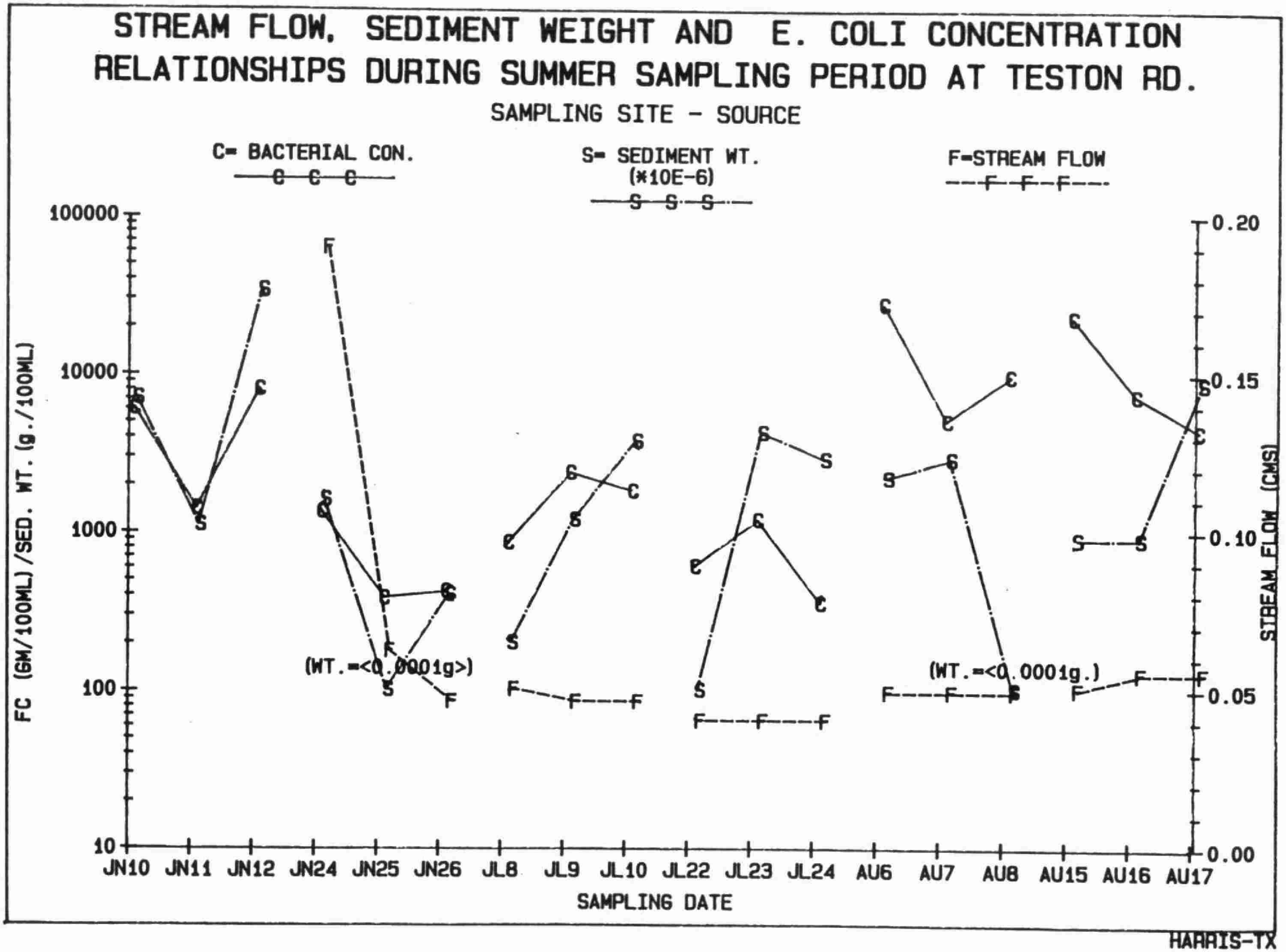
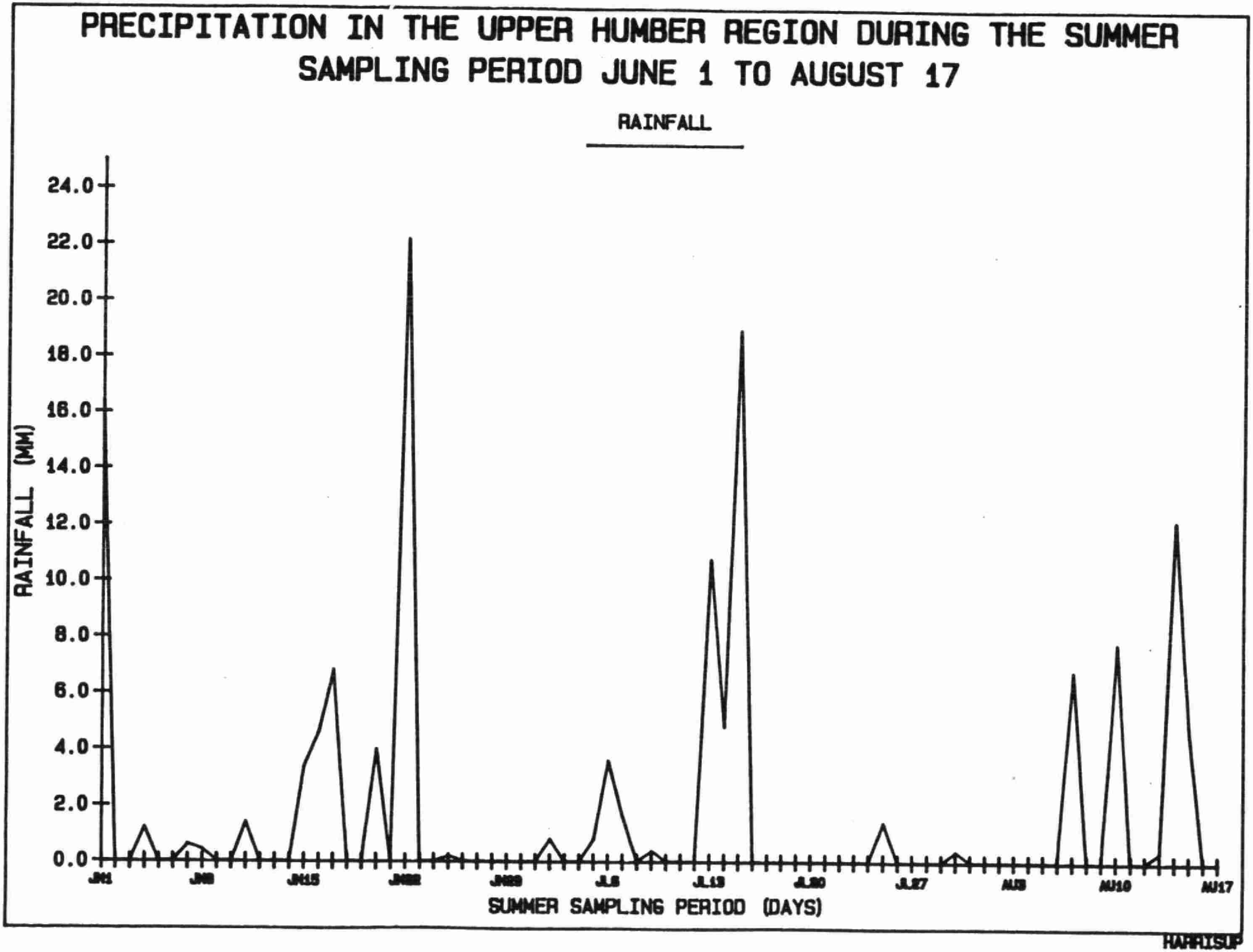

STREAM FLOW, SEDIMENT WEIGHT AND E. COLI CONCENTRATION RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT TESTON RD.
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT. (*10E-6)
F=STREAM FLOW
FC (GM/100ML)/SED. WT. (g./100ML)
100000
10000
1000
100
10
STREAM FLOW (CMS)
0.20
0.15
0.10
0.05
0.00
(WT.=<0.0001g>)
(WT.=<0.0001g.)
JN10
JN11
JN12
JN24
JN25
JN26
JL8
JL9
JL10
JL22
JL23
JL24
AU6
AU7
AU8
AU15
AU16
AU17
SAMPLING DATE
HARRIS-TX

Figure 55 :


PRECIPITATION IN THE UPPER HUMBER REGION DURING THE SUMMER SAMPLING PERIOD JUNE 1 TO AUGUST 17
RAINFALL
RAINFALL (MM)
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
SUMMER SAMPLING PERIOD (DAYS)
HARRISUP

effect of rainfall occurring on June 15, 16, 17 and 20th as well as the 22nd.

The obvious variability in SED and bacterial levels (e.g. survey 4) is probably due to day-to-day changes in cattle activity during dry weather. The increase in bacterial levels noted between day 2 and day 3 of the first and fifth survey and at the beginning of the last survey may be due to rainfall occurring in the upper Humber area (Fig. 55).

The regression analyses with S.SED levels (Table 31) demonstrates no correlation with flow, EC or FC and only one sediment to sediment comparison demonstrated a significant positive relationship, SED at DN1 vs. SED at DN2. The complexity of this location is probably due to the impact of a number of factors that are playing a significant role in elevating SED, EC and FC densities. These factors would include the input of SED and FIB from upstream, direct fecal inputs, resuspension and inputs caused by cattle movement down the banks and into the river (physical erosion).

The EC, FC regression analyses (Table 32) demonstrate a definite impact on the river at source with only one significant correlation between UP levels and other sites (EC at UP vs. EC at DN1). The tendency for an increase in the correlation coefficient at DN1 in the comparisons with UP bacterial levels and a reverse effect in the comparisons with source bacterial levels indicates a greater interaction of upstream inputs at DN1

Table 31:

Correlation Coefficients of Suspended Sediment Weights (Before Sediment Agitation) with Fecal Coliform, Escherichia coli Counts and Flow Rate at Teston Road

Sediment Weight	Sediment Weight			
	Upstream	Source	Downstream I	Downstream II
Upstream	+ 1.00	- 0.16	+ 0.18	+ 0.31
Source		+ 1.00	+ 0.01	+ 0.66
Downstream I			+ 1.00	+ 0.66
Downstream II				+ 1.00
Fecal coliforms				
Upstream	+ 0.51	- 0.16	+ 0.24	+ 0.18
Source	+ 0.31	+ 0.24	+ 0.08	+ 0.24
Downstream I	+ 0.29	- 0.06	+ 0.44	+ 0.55
Downstream II	+ 0.19	- 0.01	+ 0.32	+ 0.54
E. coli				
Upstream	+ 0.51	- 0.15	+ 0.24	+ 0.18
Source	+ 0.29	+ 0.24	+ 0.09	+ 0.24
Downstream I	+ 0.30	- 0.06	+ 0.46	+ 0.56
Downstream II	+ 0.18	- 0.01	+ 0.32	+ 0.54
Flow rate	- 0.08	- 0.03	+ 0.15	- 0.19

Table 32:

Correlation Coefficients of Fecal Coliform, Escherichia coli Counts and Flow Rate at Teston Road

	Fecal Coliforms			
E. coli	Upstream	Source	Downstream I	Downstream II
Upstream	+1.00	+0.53	+0.59	+0.55
Source	+0.52	+1.00	+0.79	+0.82
Downstream I	+0.60	+0.77	+1.00	+0.94
Downstream II	+0.53	+0.81	+0.95	+1.00
Fecal coliforms				
Upstream	+1.00	+0.51	+0.59	+0.54
Source		+1.00	+0.79	+0.82
Downstream I			+1.00	+0.95
Downstream II				+1.00
Flow rate	+0.28	+0.03	+0.10	+0.01
E. coli	E. coli			
Upstream	+1.00	+0.53	+0.61	+0.54
Source		+1.00	+0.77	+0.82
Downstream I			+1.00	+0.94
Downstream II				+1.00
Flow rate	0.26	0.03	0.10	0.01

than source or DN2. It is not apparent from the data available why this would be occurring.

Flow within the levels monitored at this site has little effect on either SED or bacteria. This is not surprising since as was noted earlier, surveys were conducted during periods of relatively constant flow while factors such as cattle activity were effecting SED and bacterial levels.

Streptococcus Populations

There is little evidence of dry weather human fecal input at Up before MSR and this continues to be the situation during wet weather (Table 33). The small representation of S. faecium var faecium could be due to a small human impact somewhere upstream but the continued high percentage of S. faecium var casseliflavus in the population and increased S. faecalis var liquefaciens are more indicative of non-human inputs. The shift to S. faecium var faecium and S. durans after MSR is probably due to their better survival characteristics rather than a build up of human fecal waste inputs.

The streptococcus populations at source and UP continue to be indicative of mixed, predominantly non-human inputs. S. bovis was not recovered at these sites probably because of its sensitivity to the natural environment and rapid die-off but Aerococcus sp. were recovered in the sediments at source and SED and water column (wet and dry) at DN1. Aerococcus sp. were found to be present in high numbers in cow feces (P. Seyfried, E. Harris and

Table 33:

Fecal Streptococcus Populations at Teston Road Under Wet and Dry Weather Conditions

Site and cond.		Total Isolates	S.faecalis faecalis	S.faecalis liquefaciens	S.faecalis zymogenes	S.faecium	S. faecium casseliflavus	S.durans	S.bovis	S.avium	Fecal Strep.	Non-fecal streptococci	Aerococcus
UPSTREAM	Dry Before	20	-	9(45.0)	-	-	7(35.0)	4(20.0)	-	-	-	-	-
	Dry After	18	-	-	-	6(33.3)	3(16.7)	7(38.9)	-	-	2(11.0)	-	-
	Wet	39	-	17(49.6)	2(5.1)	3(7.7)	14(35.9)	3(7.7)	-	-	-	-	-
SOURCE	Dry Before	18	-	10(55.5)	-	2(11.1)	2(11.1)	2(11.1)	-	-	-	2(11.1)	-
	Dry After	18	-	4(22.2)	-	1(5.6)	1(5.6)	4(22.2)	-	-	2(11.1)	-	6(33.3)
	Wet	44	2(4.5)	12(27.3)	1(2.3)	1(25.0)	7(15.9)	11(25.0)	-	-	-	-	-
DOWNSTREAM	Dry Before	25	-	6(24.0)	-	5(20.0)	2(8.0)	5(20.0)			3(12.0)	-	4(16.0)
	Dry After	24	-	4(16.6)	-	3(12.5)	8(33.3)	2(8.3)	-	-	2(8.3)	1(4.2)	4(16.6)
	Wet	37	-	11(29.7)	2(5.4)	4(10.8)	12(32.4)	5(13.5)	-	-	-	1(2.7)	2(5.4)
feces		243	2	73	5	35	56	43			9	4	16

Percentages in Parenthesis ( )

M. Young, 1986, unpublished data) and thus show the impact of the cattle.

Bacterial Survival

The die-off *E. coli* during the summer (Fig. 56, Table 34) although initially not as rapid as that at James Garden showed no decrease between 24 and 48 hrs. of exposure. The apparent decrease between 48 and 72 hrs. exposure reduced *E. coli* concentration to 1/100 ml, that is, approximately .000001 of the original density in the chamber.

S. faecalis survived better than *E. coli* at this location but it demonstrated a more rapid die-off than at James Garden. Lower nutrient levels may be a factor in this decreased survival.

Under winter conditions (Fig. 57 and Table 35) *S. faecium* and *E. coli* demonstrated protracted survival following an initial decrease of about one order of magnitude during the first 24 hrs. of exposure. The die-off in *E. coli* from 24 to 72 hrs. was negligible while *S. faecium* appeared to show an increase before continuing to decrease. It is highly unlikely that growth would occur under the existing natural conditions (low temperature plus poor nutrient levels) and thus the apparent drop in *S. faecium* during the first day of exposure followed by an increase must be considered an anomalous result probably due to sampling problems under the cold weather conditions. The overall slow die-off rate is, however, a good reflection of existing effects.

Figure 56:

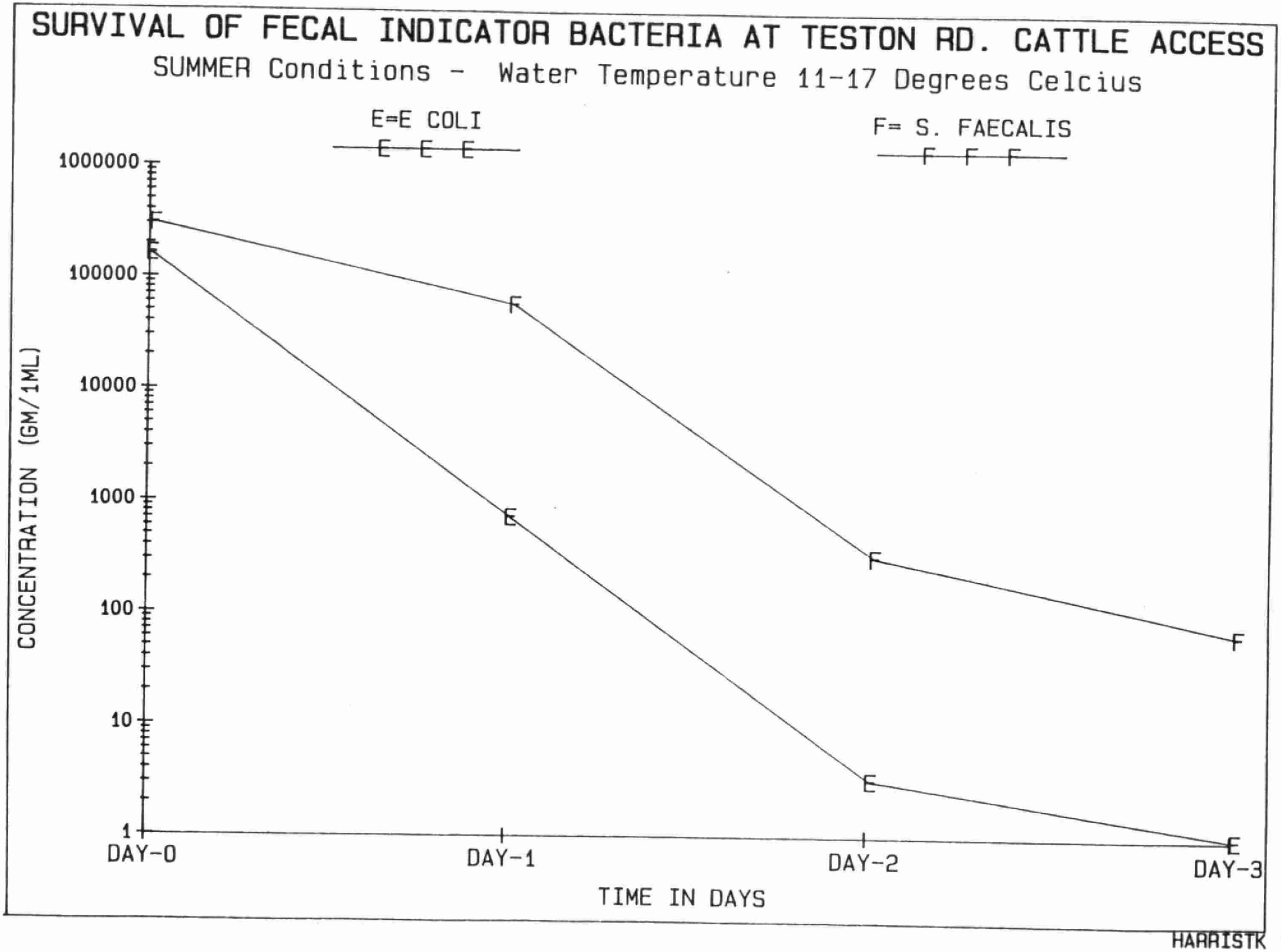

SURVIVAL OF FECAL INDICATOR BACTERIA AT TESTON RD. CATTLE ACCESS
SUMMER Conditions - Water Temperature 11-17 Degrees Celcius
E=E COLI
F= S. FAECALIS
CONCENTRATION (GM/1ML)
1000000
100000
10000
1000
100
10
1
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISTK

Table 34:

Percent die-off of fecal indicator bacteria at Teston Road Cattle access area during summer weather conditions (Average water temperature 12.8°C)

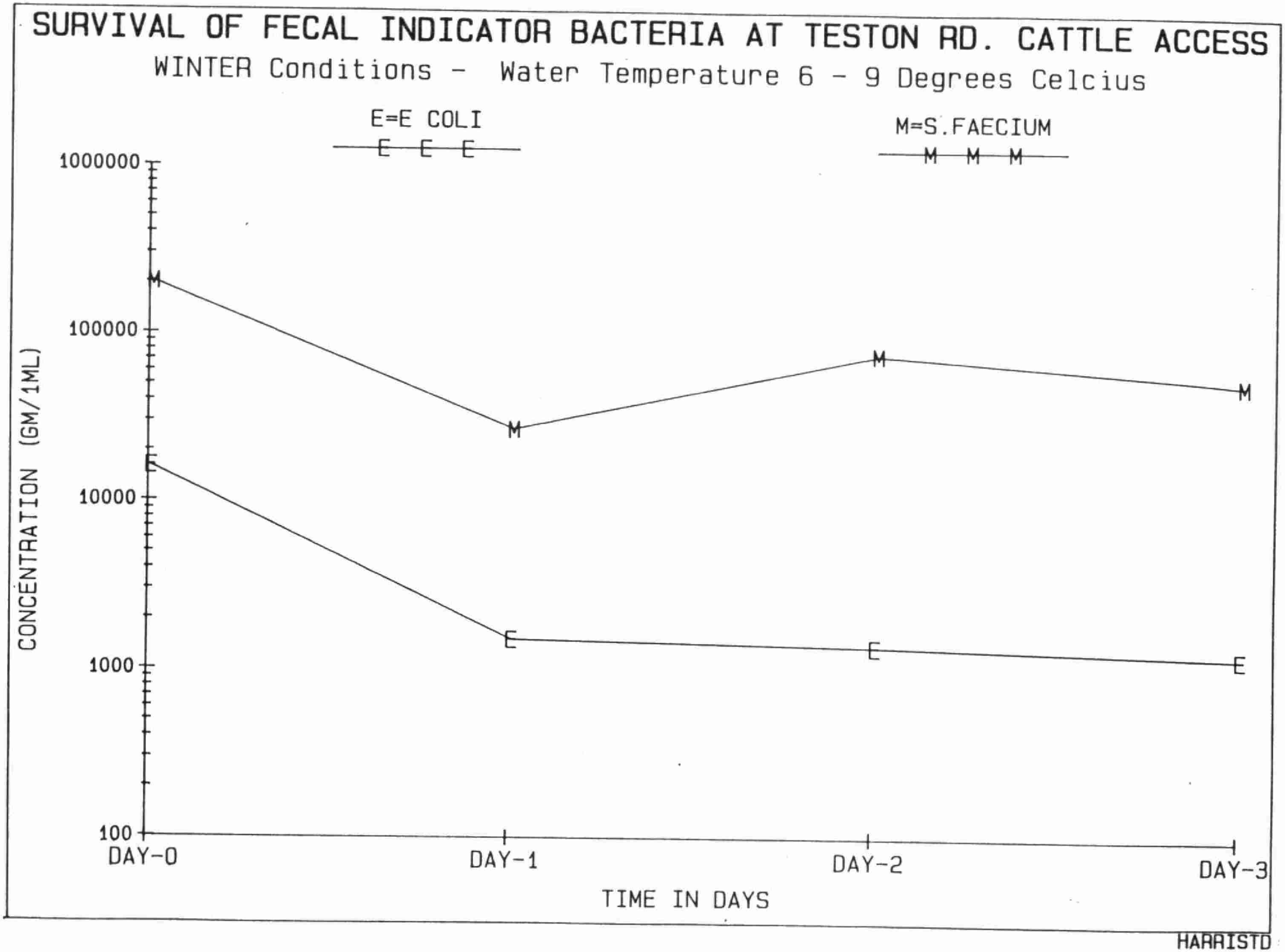
Bacterial Culture	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli (50 ml chamber)	1.6×10^5	7.2×10^2	3.2	1
Escherichia coli (100 ml chamber)	1.01×10^5	1.5×10^2	60.4	contaminated
Strep. faecalis (50 ml chamber)	3.0×10^5	5.8×10^4	3.2×10^2	67
Strep. faecalis (100 ml chamber)	1.7×10^5	3.8×10^2	5.0	contaminated

Table 35:

Percent die-off of fecal indicator bacteria at Teston Road Cattle access area during winter weather conditions (Average water temperature 8°C)

Bacterial Culture (50 ml chamber)	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli	1.6×10^4	1.5×10^3	1.3×10^3	1.2×10^3
Strep. faecium	2.0×10^5	2.7×10^4	7.6×10^4	5.2×10^4

Figure 57:


SURVIVAL OF FECAL INDICATOR BACTERIA AT TESTON RD. CATTLE ACCESS
WINTER Conditions - Water Temperature 6 - 9 Degrees Celcius
E=E COLI
M=S.FAECIUM
1000000
100000
10000
1000
100
CONCENTRATION (GM/1ML)
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISTD

It is obvious that survival of the type noted during winter conditions at Teston Road would extend the impact of pollution inputs even farther than at James Garden. This indicates that impacts, of the type that can occur in agricultural areas as a result of poor land use practices, could have severe consequences for quite a distance downstream on small tributaries with colder water.

Bolton (Sewage Treatment Plant)

Sediment Resuspension

Sediment

The water column SED levels, before MSR, are quite variable demonstrating different patterns of increase and decrease under different weather conditions (Fig. 58, Table 36).

Suspended SED increases in the water column at source and DN2 are not likely due to the STP effluent since its SED densities are the same as those observed at UP. The cause is probably due to sediment resuspension occurring between UP and DN2. At source the resuspension could be due to the effluent impact and at DN2 the cause may be increased resuspension and/or erosion as the river rounds a bend between DN1 and DN2. This same phenomenon was noted at the Elhart Drive DN2 site.

The decrease in S.SED levels noted at source during wet weather could be an effect of the STP effluent plume which has SED densities one-fifth of those at UP. It is also evident that

Figure 58:

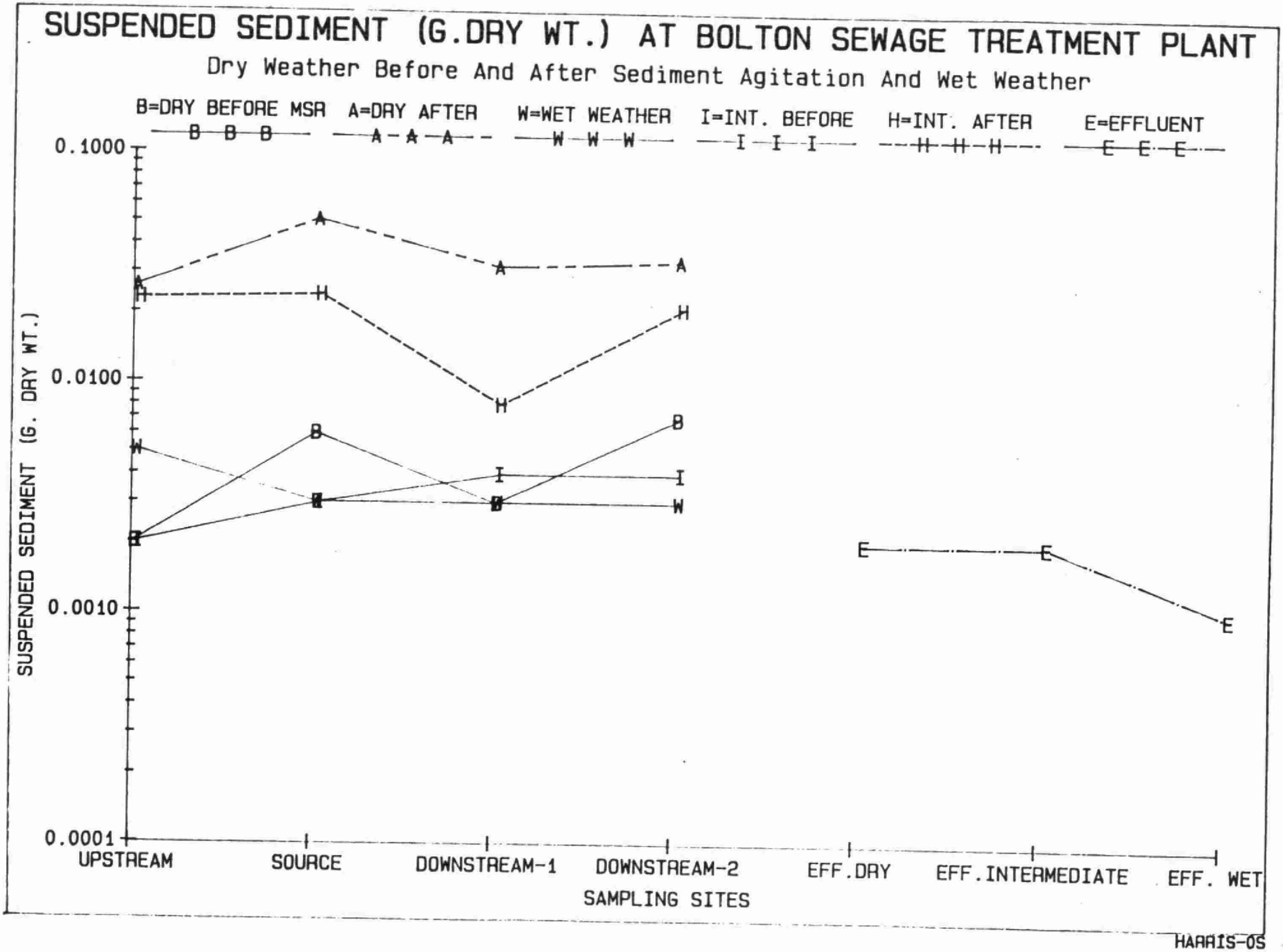

SUSPENDED SEDIMENT (G.DRY WT.) AT BOLTON SEWAGE TREATMENT PLANT
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=EFFLUENT
0.1000
0.0100
0.0010
0.0001
SUSPENDED SEDIMENT (G. DRY WT.)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
EFF.DRY
EFF.INTERMEDIATE
EFF. WET
SAMPLING SITES
HARRIS-OS

Table 36:

Geometric mean concentrations of Fecal Indicator Bacteria, E. coli to Fecal Coliform ratios, Fecal Coliform to Fecal Streptococci Ratios and Suspended Sediment Weights During Dry and Intermediate Weather (Before and After Sediment Agitation) and Wet Weather at Bolton Sewage Treatment Plant.

Sampling site and weather cond.	Fecal coliforms	E. coli	Fecal Streptococci	Enterococci	P. aeruginosa	EC/FC Ratio	FC/FS Ratio	Suspended sediment (grams/100mls)
	(per 100 ml water sample)							
upstream B	274	264	170	127	2.5	0.96	1.6	0.002
dry A	445	411	206	142	3.7	0.92	2.2	0.026
Int. B	257	194	122	154	1.0	0.75	2.1	0.002
A	891	871	390	279	2.4	0.98	2.3	0.023
wet	668	486	461	321	9.4	0.73	1.4	0.005
source B	279	261	188	93	2.0	0.93	1.5	0.006
dry A	591	547	265	195	3.9	0.93	2.2	0.051
Int. B	725	690	259	144	6.6	0.95	2.8	0.003
A	970	894	326	248	5.1	0.92	3.0	0.024
wet	744	542	453	392	12.8	0.73	1.6	0.003
downstream I								
dry B	240	204	216	147	1.9	0.85	1.1	0.003
A	428	389	249	162	3.2	0.91	1.7	0.032
Int. B	690	673	322	214	1.0	0.98	2.1	0.004
A	997	937	314	207	2.0	0.94	3.2	0.008
wet	588	489	491	303	12.9	0.83	1.2	0.003
downstream II								
dry B	353	325	178	133	2.5	0.92	2.0	0.007
A	446	418	239	150	3.4	0.94	1.9	0.034
Int. B	1,935	984	152	288	8.5	0.51	12.7	0.004
A	1,881	1,834	694	265	3.5	0.98	2.7	0.021
wet	579	476	471	383	17.0	0.82	1.2	0.003
Effluent dry	104	80	44	36	3.3	0.78	2.4	0.002
Int	453	452	172	549	915	1.0	2.6	0.002
wet	84	70	28	37	6.1	0.83	3.0	0.001

the S.SED levels impacting from upstream are not as elevated during wet weather as at the other sites.

The gradual increase in SED concentrations from UP to DN1 during intermediate conditions is once again most likely due to SED resuspension.

The effect of MSR during dry weather indicates SED deposition at all sites, particularly source. During intermediate conditions there is a net decrease in suspended sediment deposits particularly at DN1. This is most likely due to the effect of the preceding storm event. It could be that the redeposition of SED during dry weather is one cause of the lower SED levels, before MSR, at DN1.

Bacteria

There is only a small effect on FIB levels in the Humber River resulting from the input of the STP effluent during dry weather (before and after MSR) and during wet weather (Figs. 59-63 and Table 36). Under these weather conditions it was observed that the effluent FIB levels were well below those entering the location from upstream. The only bacterial species found in slightly higher concentration in the effluent during dry weather than in the water column at UP was PSA (Fig. 63) but even this organism did not exhibit a significant response. In fact the PSA densities decreased at source and DN1.

The drop in concentration of some of the FIB at source and perhaps DN1 to a lesser extent may be due to the presence of a

Fi[redacted]e [redacted]

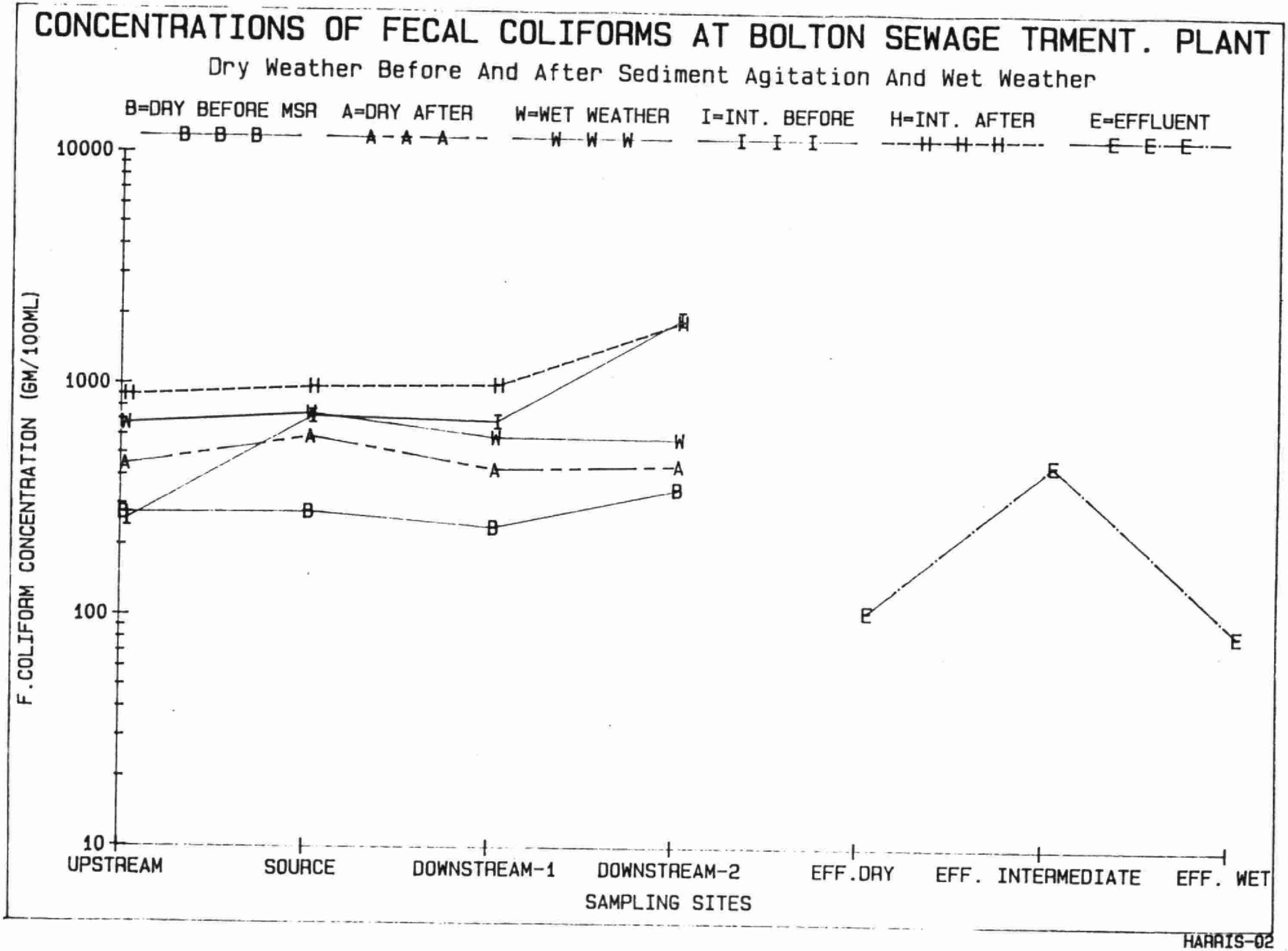


Figure 60:

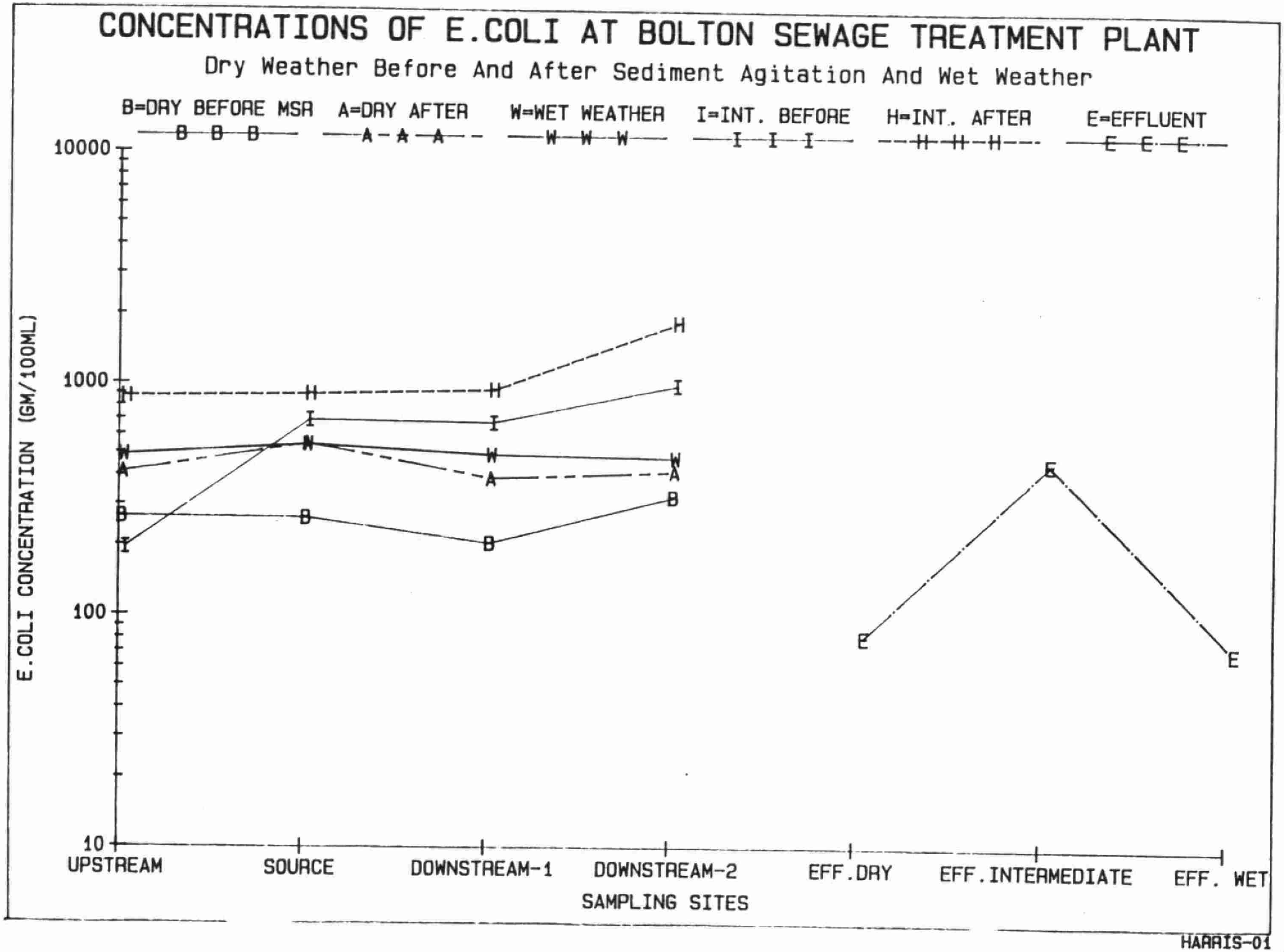
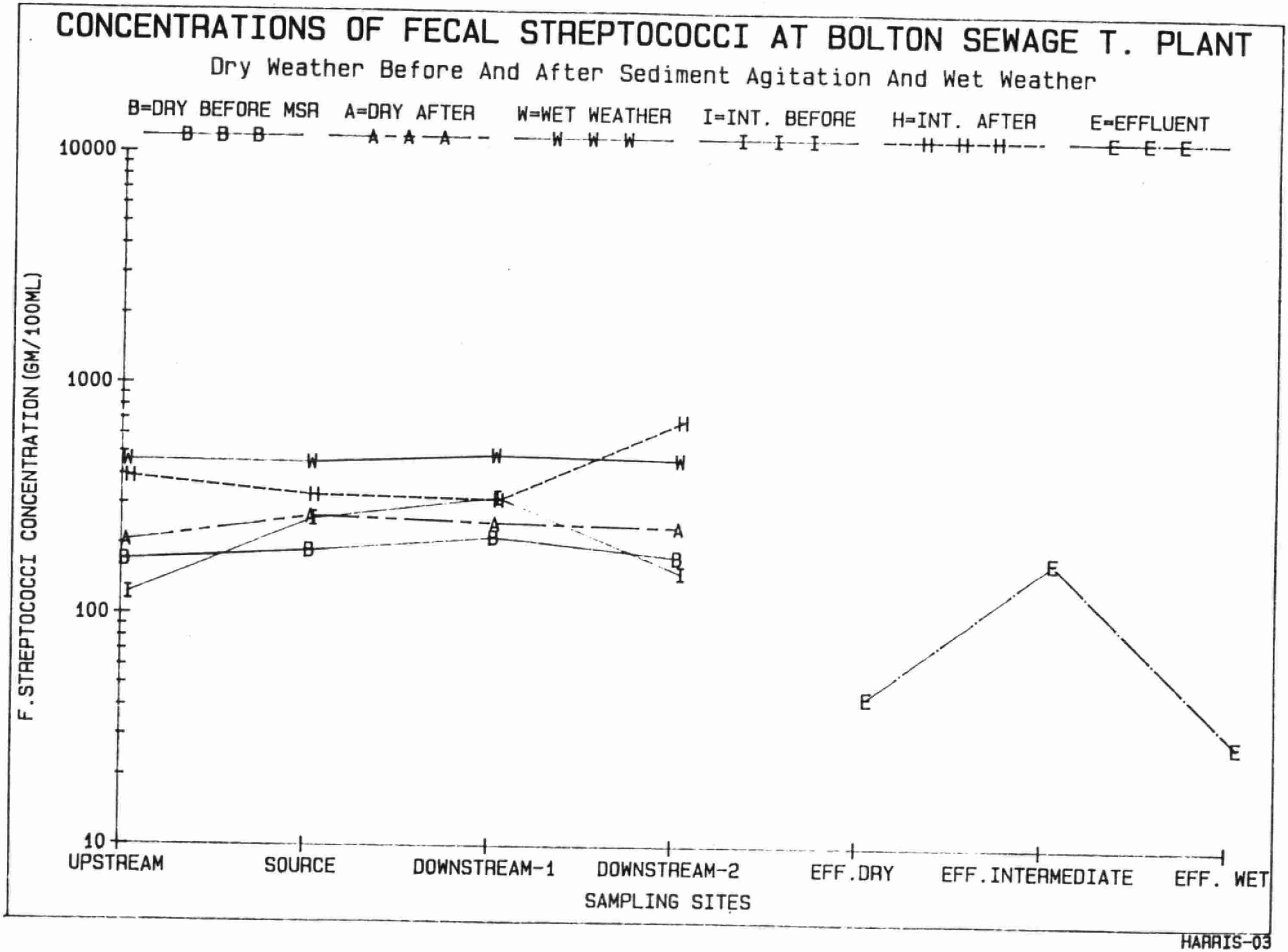
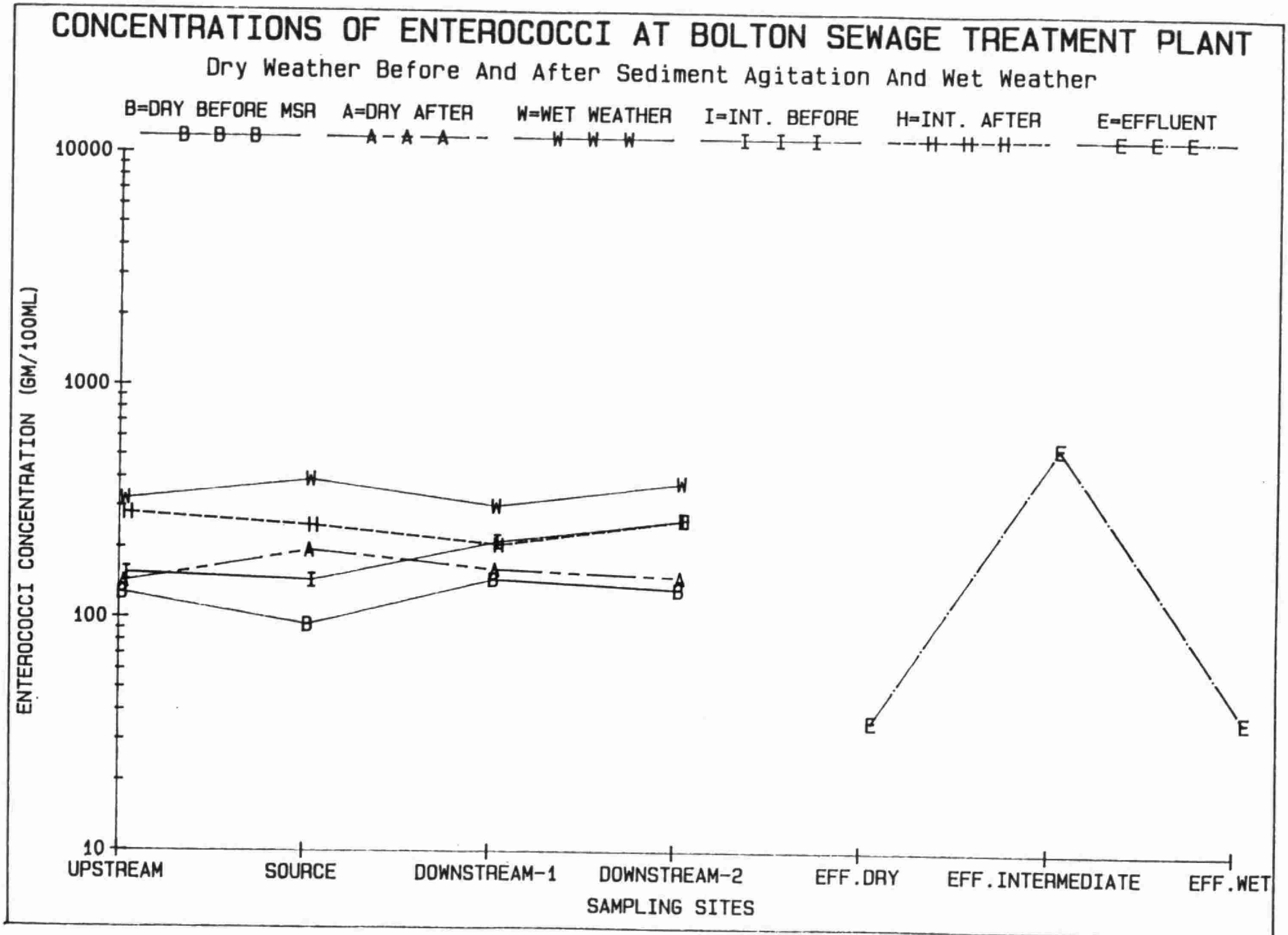

CONCENTRATIONS OF E.COLI AT BOLTON SEWAGE TREATMENT PLANT
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=EFFLUENT
E.COLI CONCENTRATION (GM/100ML)
10000
1000
100
10
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
EFF.DRY
EFF.INTERMEDIATE
EFF. WET
SAMPLING SITES
HARRIS-01

Figure 6



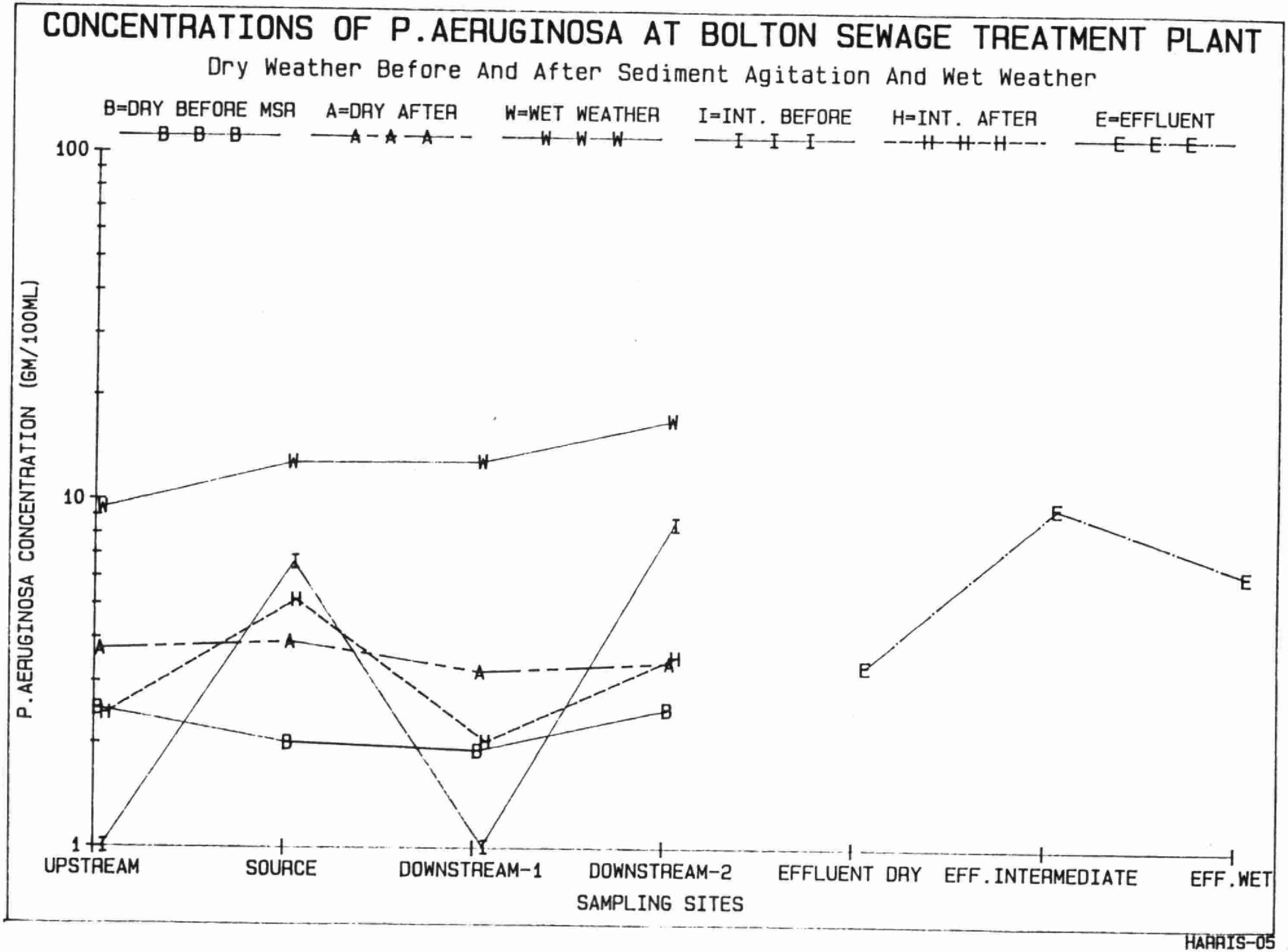
CONCENTRATIONS OF FECAL STREPTOCOCCI AT BOLTON SEWAGE T. PLANT
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=EFFLUENT
10000
1000
100
10
F.STREPTOCOCCI CONCENTRATION (GM/100ML)
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
EFF.DRY
EFF.INTERMEDIATE
EFF. WET
SAMPLING SITES
HARRIS-03

Figure 62:



HARRIS-04

Fi[redacted]e [redacted]



chlorinated effluent. Since sites were positioned within the effluent plume, deposition and dilution will also affect FIB decreases. The decrease of PSA, an organism resistant to chlorine at source may be due in part to the increased stress on the bacteria entering the aquatic environment. PSA generally do not survive as well in the water column as other FIB, unless there is a high nutrient input (41).

The increase in FC (Fig. 59), EC (Fig. 60) and PSA at DN2 during dry weather before MSR is probably related to resuspension and transportation of bed sediments and not the STP. The same is true of the gradual increase in PSA under wet weather conditions. THe ability of PSA to survive and reproduce under appropriate conditions (i.e. in sediments receiving high nutrient inputs) may be the reason for the greater response obtained from this bacteria in comparison to the others. The presence of an unmarked storm sewer between DN1 and DN2 could also cause an impact on water quality during wet weather causing FIB concentrations at DN2 to be maintained at similar levels as those at DN1 (Fig. 63); FC, EC, FS (Fig. 61) or increased; ENT (Fig. 62) and PSA.

The FIB concentrations at UP during dry and wet conditions indicate that there are ongoing pollution inputs upstream of the Bolton location. Some of the impact could come from septic seepage of improperly placed or over-loaded septic systems. Problems such as these have been observed in the upstream area.

During intermediate conditions the concentrations of FIB were higher in the STP effluent than those entering the study location from upstream. The data indicates that during this sampling period the STP was overloaded and by-passing, probably due to infiltration of the sanitary system during wet weather. Increased flows were observed by samplers during intermediate condition sampling. In addition FIB concentrations in the water column at UP tended to be the lowest observed during intermediate conditions, before MSR. The net effect of the reduced upstream FIB densities and increased effluent levels was to produce a demonstrable impact on FIB water quality at source, except for ENT levels. There is no obvious explanation for the delayed ENT response particularly since it is present in the greatest concentration in the STP effluent. The increase in FIB concentrations before MSR, that is observed at DN2, may in part be due to sediment resuspension but the storm sewer between DN1 and DN2 is also suspected.

The FIB levels demonstrated following MSR during intermediate conditions appear to be increased by the deposition of contaminated sediment following wet weather. Concentrations in the SED are higher than observed during dry weather conditions except for PSA at UP and DN1. PSA is also the only bacterial indicator to show a response at source following MSR. Once again this may be related to its ability to survive and sometimes reproduce in bed sediments.

The increase noted at DN2 following MSR is indicative of the accumulation of contaminated sediments during intermediate conditions. The contaminant loadings would be a combination of those brought from upstream plus additional inputs from the STP and storm sewer and downstream site to site transfer of contaminated SED within the location.

FC/FS

The effluent FC/FS ratios (Fig. 64 and Table 36) are low and only slightly higher than those existing instream at UP. The low effluent ratios are probably due to the ongoing treatment process and dilution effects. The input of the effluent causes only a small increase in FC/FS at source during intermediate and wet conditions and the ratio tends to decrease from UP to DN1 during dry weather before and after MSR.

The decrease in FC/FS during dry weather is probably due to the presence of chlorine in the effluent which will have a more detrimental effect on FC than FS. The reverse effect (i.e. less efficient treatment within the plant) would cause a somewhat greater increase in FC.

The major increase in FC/FS at DN2 during intermediate conditions, before MSR, cannot be attributed directly to the STP effluent but could be due to sediment resuspension or inputs from the storm sewer downstream. The problems with water quality noted at DN2 would suggest that an investigation of the storm sewer between DN1 and DN2 should be conducted.

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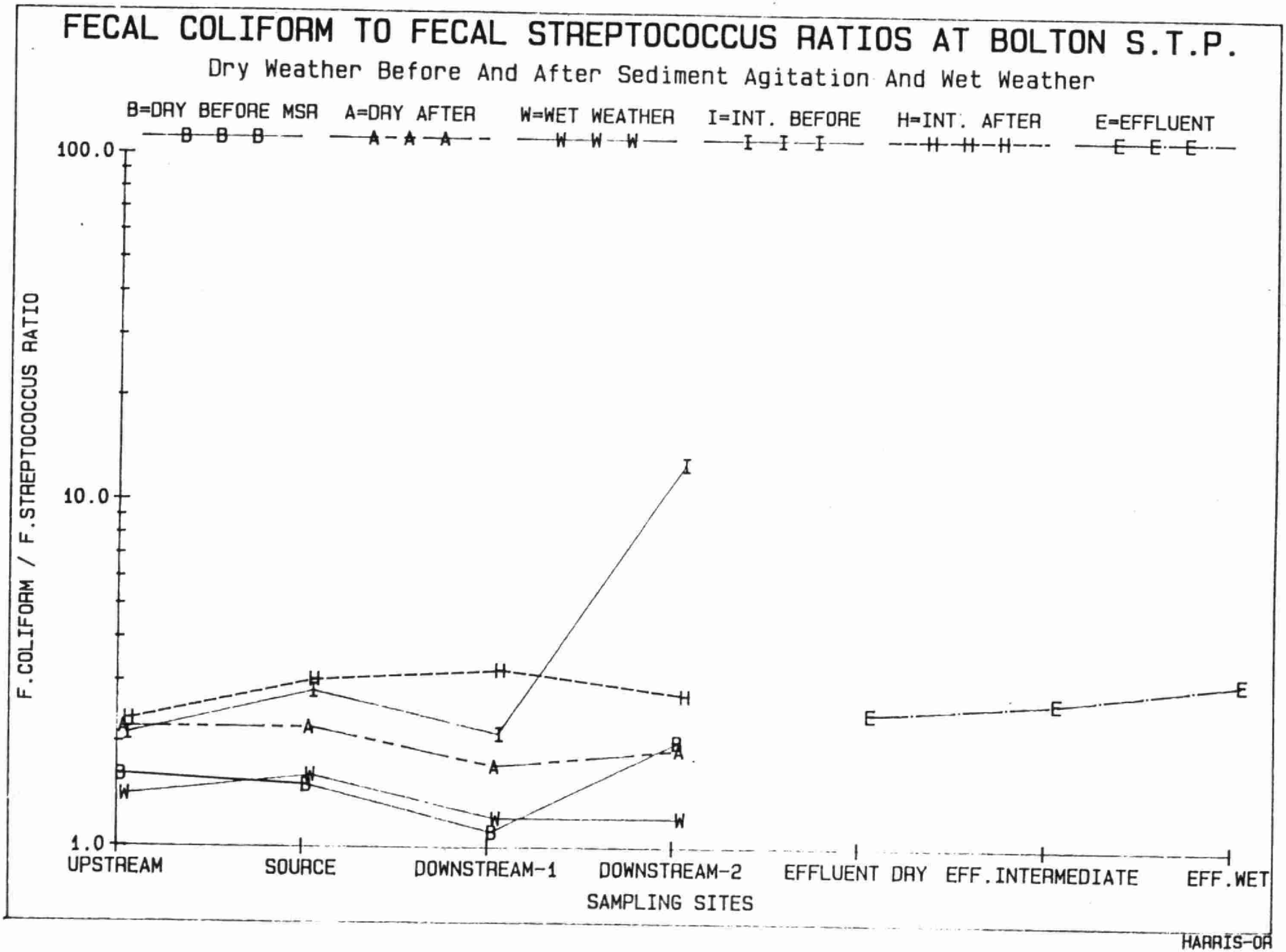

FECAL COLIFORM TO FECAL STREPTOCOCCUS RATIOS AT BOLTON S.T.P.
Dry Weather Before And After Sediment Agitation And Wet Weather
B=DRY BEFORE MSR
A=DRY AFTER
W=WET WEATHER
I=INT. BEFORE
H=INT. AFTER
E=EFFLUENT
100.0
10.0
1.0
F.COLIFORM / F.STREPTOCOCCUS RATIO
UPSTREAM
SOURCE
DOWNSTREAM-1
DOWNSTREAM-2
EFFLUENT DRY
EFF.INTERMEDIATE
EFF.WET
SAMPLING SITES
HARRIS-OR

Post-Rainfall Bacterial (EC/FC) Quality

The post-rainfall EC and FC data (Table 37) demonstrate different responses instream and in the STP effluent. The Humber River sites demonstrate the presence of increased wet weather bacterial loadings but the fecal contamination present is of less recent origin than during the following four days of the study. Inputs during wet weather could include storm runoff from Bolton, septic seepage and agricultural land runoff.

The EC and FC concentrations following wet weather show some fluctuation but are always below wet weather levels and their ratio indicates that although contaminant loadings have decreased they are of a more recent nature, probably from inputs closer to the study area. The occasional drop in the EC/FC ratio at DN1 and DN2 may be due to impacts from the effluent which at times appears to have lower EC/FC ratios than observed instream. As indicated before, DN2 may also be impacted by the storm sewer situated above it in the river.

The STP effluent post-rainfall data show two main differences in the instream data; 1) the wet weather EC/FC ratio is highest with a tendency to decrease during the following four days and 2) wet weather EC and FC concentrations were not the highest observed. These differences undoubtedly relate to the relative level of efficiency of treatment at any given time on effluent bacterial levels and the effects of overloading that can occur following a storm event.

Table 37:

Escherichia Coli to Fecal Coliform Ratios during Post-Rainfall Period at Bolton Sewage Treatment Plant

Site	Number of Days Following Rainfall 0	1	2	3	4
UB	1900/4200 (0.45)	326/395 (0.83)	325/346 (0.94)	180/180 (1.0)	353/358 (0.99)
UA		294/323 (0.91)	511/550 (0.93)	300/328 (0.91)	615/646 (0.95)
SB	2000/6600 (0.30)	354/402 (0.98)	378/429 (0.88)	248/248 (1.0)	334/346 (0.96)
SA		549/589 (0.93)	721/824 (0.88)	512/512 (1.0)	676/712 (0.95)
DN1B	3100/8400 (0.37)	312/324 (0.96)	269/322 (0.84)	120/200 (0.60)	292/309 (0.94)
DN1A		450/484 (0.93)	374/439 (0.85)	508/556 (0.91)	587/600 (0.98)
DN2B	2300/6700 (0.34)	311/324 (0.96)	556/832 (0.67)	232/248 (0.94)	400/431 (0.93)
DN2A		485/522 (0.93)	898/952 (0.94)	260/310 (0.84)	561/587 (0.96)
EFF	300/300 (1.0)	50/60 (0.83)	542/557 (0.97)	116/168 (0.69)	39/57 (0.68)

E.coli / F. coliforms (Ratio) *approximate value

The EC/FC ratios obtained from the mean values (Table 36) demonstrate similar trends as the post-rainfall levels. The major differences noted are the decrease in EC/FC at UP and DN2 during intermediate conditions, before MSR. At UP the decrease means that on average, the impact of more distant, less recent, fecal inputs from upstream continues to occur even though flows decrease during intermediate conditions. This effect is not felt at source of DN1 because of the STP input.

The low EC/FC at DN2 is primarily due to a major increase in the FC levels (i.e. $\triangle$ EC DN1-DN2 = 311, $\triangle$ FC DN1-DN2 = 1245). Since upstream data, before and after MSR, cannot account for the change in water quality and the FC/FS ratio also indicated an input, as did PSA levels, the presence of the unidentified storm sewer above DN2 subjects it to suspicion as the cause of water quality degradation in this area.

Natural Environmental Phenomena and Bacterial Concentrations

The variability of the daily observations made at this location (Fig. 65 and 66) are greater than at other locations. There is not one survey in which flow, SED and bacterial concentrations follow similar day-to-day changes in magnitude.

The first three surveys occurred during periods of decreasing flow. During the first two surveys bacterial levels appeared to be stabilizing while during the third the densities increased slightly. The increase in FC and EC could be due to the continued after-effect of a small amount of rainfall on June

Figure [redacted]:

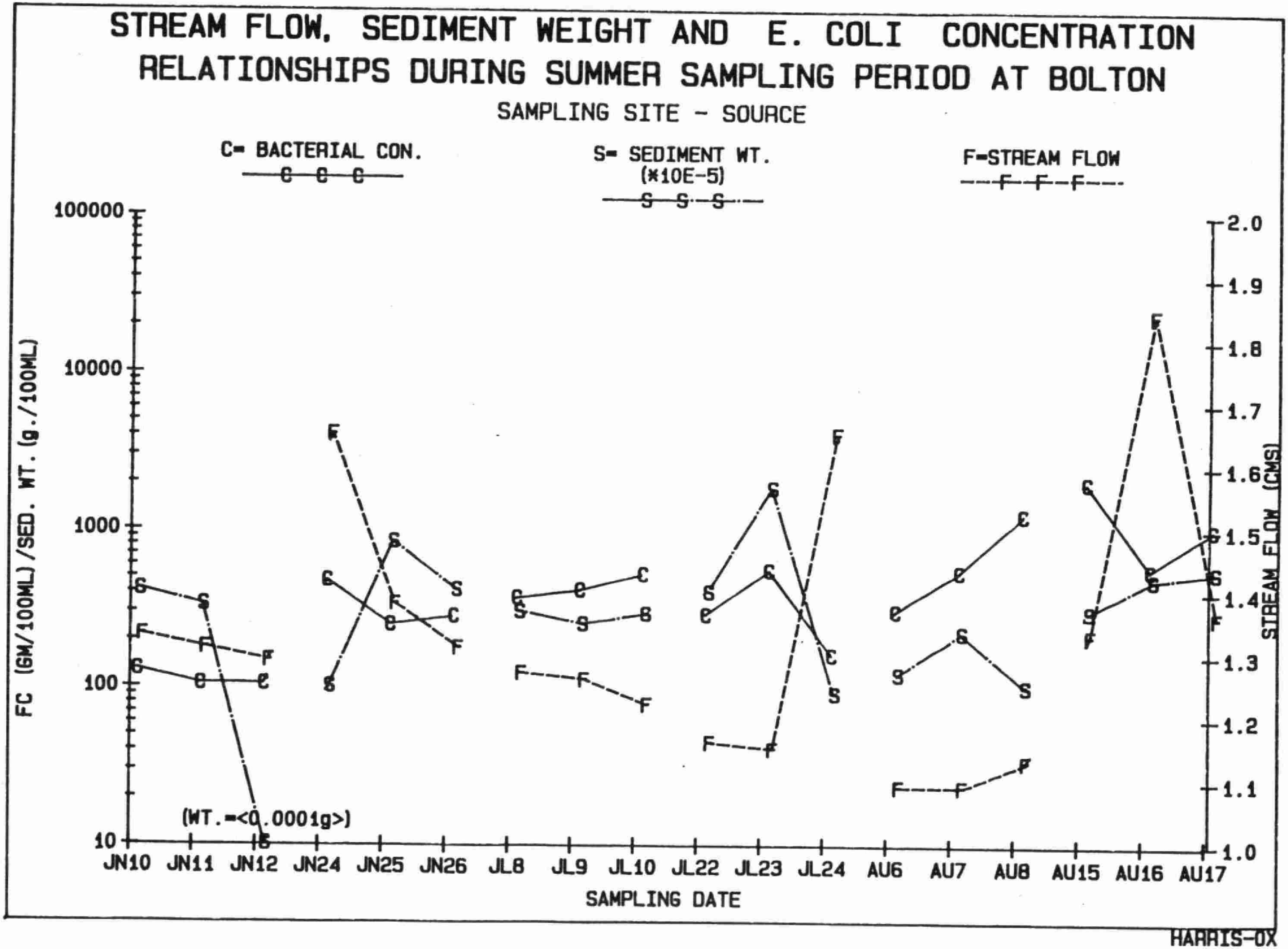
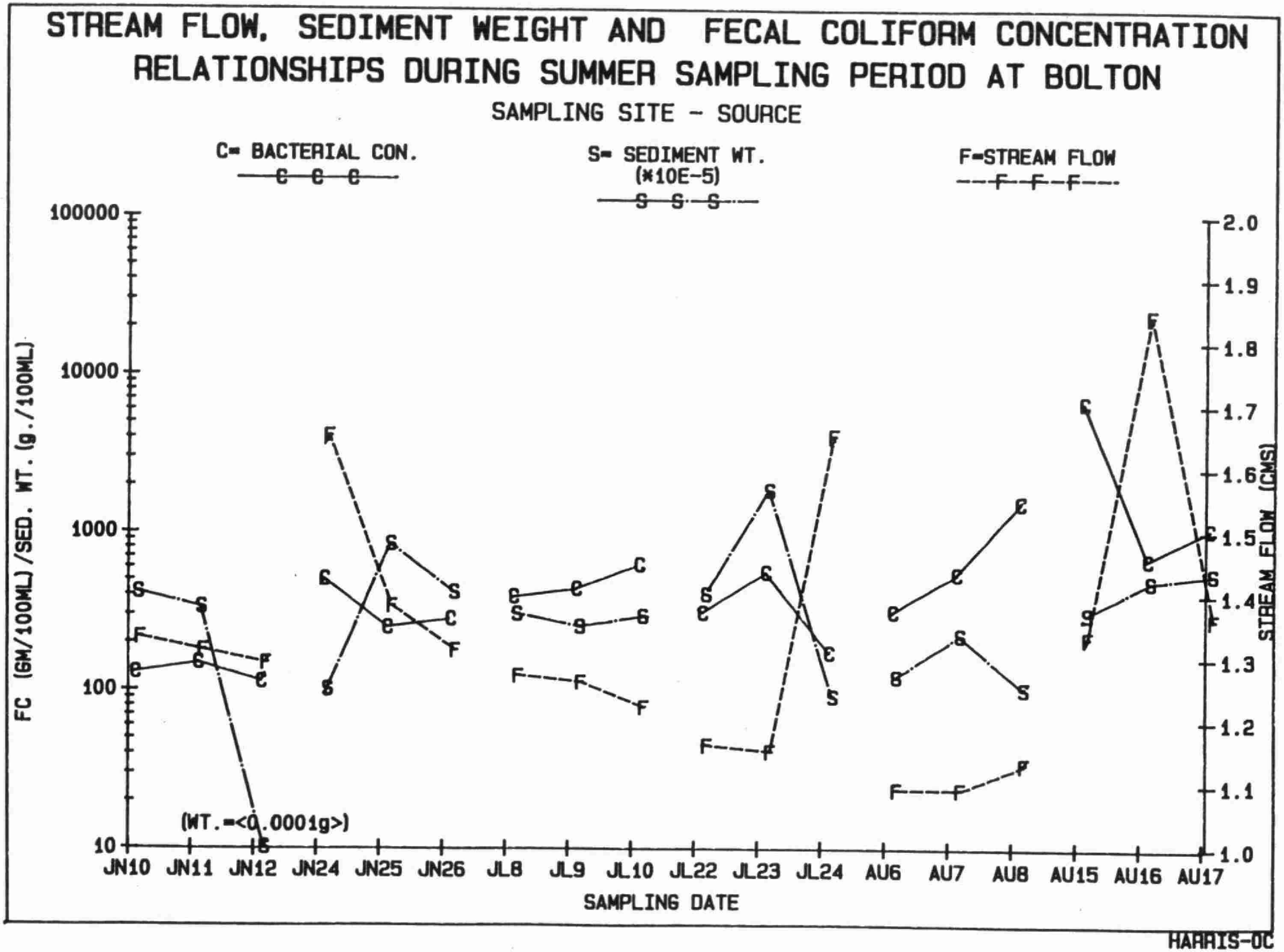


Figure 66:


STREAM FLOW, SEDIMENT WEIGHT AND FECAL COLIFORM CONCENTRATION
RELATIONSHIPS DURING SUMMER SAMPLING PERIOD AT BOLTON
SAMPLING SITE - SOURCE
C= BACTERIAL CON.
S= SEDIMENT WT. (*10E-5)
F=STREAM FLOW
FC (GM/100ML)/SED. WT. (g./100ML)
STREAM FLOW (CMS)
(WT.=<0.0001g>)
100000
10000
1000
100
10
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
JN10 JN11 JN12 JN24 JN25 JN26 JL8 JL9 JL10 JL22 JL23 JL24 AU6 AU7 AU8 AU15 AU16 AU17
SAMPLING DATE
HARRIS-OC

6 and 7, and/or inputs from the STP. The SED, however, only showed some stability in levels during the third survey.

The increase in SED and bacteria during the fourth survey (July 23, 1985) and the increase in flow on the day following (July 24, 1985) cannot be related to a rainfall event. It is possible for the STP effluents to alter instream concentrations of SED and bacteria but it is hard to conceive of a sufficient increase in effluent volume causing rise in the Humber River at this location.

The changes in parameters noted during the final two surveys appear related to rainfall events. The effect of the storm events on each of the parameters does not, however, coincide.

The sediment regression analyses (Table 38) reflects the extreme variability of this location. The changes in SED densities at any one site do not relate to changes occurring at other sites and no correlations were found with the EC, FC or flow.

The EC, FC regression analyses (Table 39) suggest that during dry weather both parameters are subjected to similar impacts throughout this location, except at DN2. The DN2 site demonstrates the lowest correlation coefficients and in three instances they are non-significant (EC UP vs. FC DN2; EC DN2 vs. FC UP and EC UP vs. EC DN2). The results suggest that upstream contamination dominates the bacterial levels except at DN2 where an additional impact is felt.

Table 38:

Correlation Coefficients of Suspended Sediment Weights (Before Sediment Agitation) with Fecal Coliform, Escherichia coli Counts and Flow Rate at Bolton Sewage Treatment Plant

Sediment Weight	Sediment Weight			
	Upstream	Source	Downstream I	Downstream II
Upstream	+ 1.00	+ 0.22	+ 0.45	+ 0.08
Source		+ 1.00	+ 0.51	+ 0.13
Downstream I			+ 1.00	+ 0.26
Downstream II				+ 1.00
Fecal coliforms				
Upstream	+ 0.40	- 0.01	+ 0.08	- 0.39
Source	+ 0.48	- 0.001	- 0.01	- 0.26
Downstream I	+ 0.55	- 0.07	+ 0.08	- 0.29
Downstream II	+ 0.49	+ 0.03	+ 0.15	- 0.21
E. coli				
Upstream	+ 0.19	- 0.03	- 0.03	- 0.44
Source	+ 0.34	+ 0.04	- 0.02	- 0.37
Downstream I	+ 0.48	- 0.10	+ 0.11	- 0.33
Downstream II	+ 0.43	- 0.02	+ 0.13	- 0.26
Flow rate	+ 0.29	+ 0.05	+ 0.52	+ 0.11

Table 39:

Correlation Coefficients of Fecal Coliform, Escherichia coli Counts and Flow Rate at Bolton Sewage Treatment Plant

	Fecal Coliforms			
E. coli	Upstream	Source	Downstream I	Downstream II
Upstream	+ 0.96	+ 0.84	+ 0.82	+ 0.57
Source	+ 0.90	+ 0.97	+ 0.87	+ 0.77
Downstream I	+ 0.89	+ 0.88	+ 0.97	+ 0.77
Downstream II	+ 0.59	+ 0.71	+ 0.74	+ 0.95
Fecal coliforms				
Upstream	+ 1.00	+ 0.91	+ 0.90	+ 0.67
Source		+ 1.00	+ 0.92	+ 0.80
Downstream I			+ 1.00	+ 0.82
Downstream II				+ 1.00
Flow rate	0.29	+ 0.02	+ 0.16	+ 0.25
E. coli	E. coli			
Upstream	+ 1.00	+ 0.87	+ 0.81	+ 0.49
Source		+ 1.00	+ 0.86	+ 0.69
Downstream I			+ 1.00	+ 0.72
Downstream II				+ 1.00
Flow rate	- 0.11	- 0.02	+ 0.21	+ 0.30

The daily data (Fig. 65, 66) indicated no correlation between EC, FC and flow.

The need for a much more intensive study to examine relationships between different field parameters and natural phenomena is once more made obvious.

Streptococcus Populations

The species distribution of the streptococci populations (Table 40) in the Bolton STP effluent under both wet and dry conditions, reflect the impact of the human sanitary waste the plant is treating. The proportionally higher representation of S. faecium var faecium than found in human feces (P. Seyfried, E. Harris and M. Young, 1986 unpublished data) is probably due to its survival characteristics (42).

The shift in streptococcus populations during wet and dry (before and after MSR) weather conditions demonstrates the impact of the effluent at source and DN1 primarily by increasing the S. faecium var faecium densities. The higher proportional representation of S. faecalis var liquefaciens in the sediment is due to the overlapping inputs from upstream that possibly contain non-human fecal waste. It is apparent however, that some human fecal pollution of the water column is occurring somewhere above the study location.

The major effect of wet weather inputs on the Humber River is to increase the relative proportion of non-human/non-fecal

Table 40:

Fecal Streptococcus Populations at Bolton Sewage Treatment Plant Under Wet and Dry Weather Conditions

Site and cond.		Total Isolates	S.faecalis faecalis	S.faecalis liquefaciens	S.faecalis zymogenes	S.faecium	S. faecium casseliflavus	S.durans	S.bovis	S.avium	Fecal Strep.	Non-fecal streptococci	Aerococcus
UPSTREAM	Dry Before	20	1(5.0)	3(15.0)	-	7(35.0)	1(5,0)	6(30.0)	-	-	2(10.0)	-	-
	Dry After	20	1(5.0)	3(15.0)	-	6(30.0)	2(10.0)	5(25.0)	-	-	1(5.0)	2(10.0)	-
	Wet	53	6(11.3)	3(5.7)	11(20.8)	11(20.8)	2(3.8)	16(30.2)	1(1.9)	3(5.7)	-	-	-
SOURCE	Dry Before	18	1(5.6)	1(5.6)	-	8(44.4)	-	7(39.9)	-	-	-	1(5.6)	-
	Dry After	20	1(5.0)	3(15.0)	-	9(45.0)	-	6(30.0)	-	1(5.0)	-	-	-
	Wet	44	8(18.2)	4(9.1)	6(13.6)	14(31.8)	4(9.1)	7(15.9)	1(2.3)	-	-	-	-
DOWNSTREAM	Dry Before	18	1(5.6)	1(5.6)	1(5.6)	12(60.7)	-	2(11.1)	-	1(5.6)	-	-	-
	Dry After	20	1(5.0)	8(40.0)	-	9(45.0)	-	-	-	-	2(10.0)	-	-
	Wet	36	7(19.4)	3(8.3)	3(8.3)	13(36.1)	3(8.3)	7(19.4)	-	-	-	-	-
EFFLUENT	Dry Before	19	1(5.3)	3(15.8)	-	12(63.2)	-	3(15.8)	-	-	-	-	-
	Dry After	NS	-	-	-	-	-	-	-	-	-	-	-
	Wet	23	6(26.1)	-	1(4.3)	14(60.9)	-	2(8.7)	-	-	-	-	-
Total column		291	34	32	22	115	12	61	2	5	5	3	

Percentages in Parenthesis ( )

inputs. It is interesting to note that S. bovis (animal origin) was isolated from UP and source samples during wet weather.

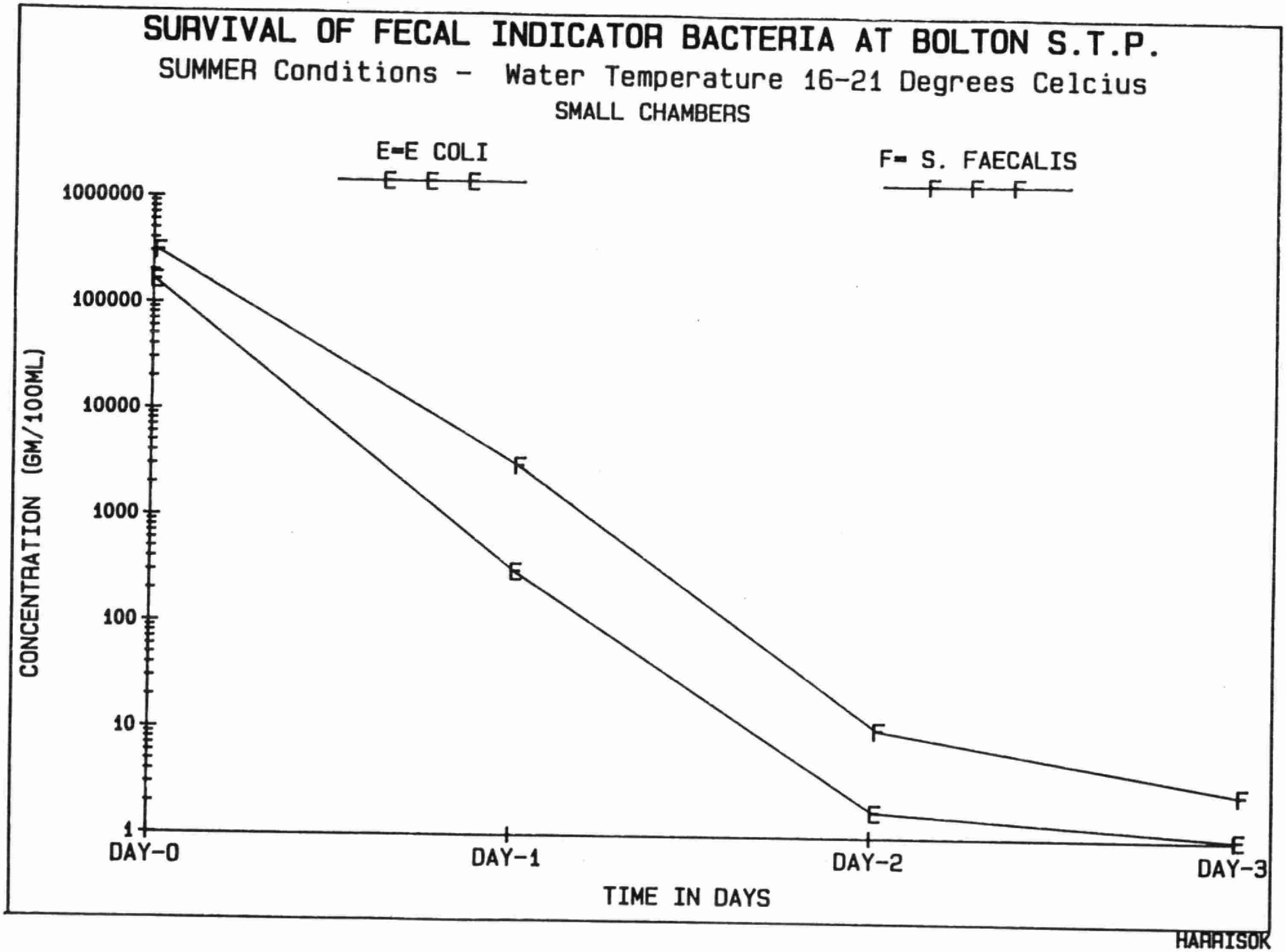
Bacterial Survival

Two sizes of chambers were used at this location to assess their relative practicality for field studies and any differences that might affect accurate data collection.

The standard size diffusion chamber (50 ml) was found to be much easier to manipulate and less prone to serious problems such as contamination during field exposure.

The die-off rates in the standard chamber (Fig. 67 and Table 41) demonstrated rapid die-off by both E. coli and S. faecalis with S. faecalis having somewhat better survival. Both bacteria showed a decrease in die-off during the last 24 hrs.

The results from the large chamber (100 ml) (Fig. 68) demonstrated a reverse effect on the two bacteria. The S. faecalis die-off rate increased while that of E. coli decreased. A decrease might be expected because of an increase in nutrient dilution that could be caused by the greater volume and the much larger surface area of the membrane exposed to the environment. The increase in survival of E. coli, however, cannot be explained by the change in chamber size and because of the handling difficulties with the large chambers experienced by field staff and the contamination problems, this data is suspect. Since similar difficulties prevailed, regardless of bacterial type



SURVIVAL OF FECAL INDICATOR BACTERIA AT BOLTON S.T.P.
SUMMER Conditions - Water Temperature 16-21 Degrees Celcius
SMALL CHAMBERS
E=E COLI
F= S. FAECALIS
1000000
100000
10000
1000
100
10
1
CONCENTRATION (GM/100ML)
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISOK

Table 41:

Percent die-off of fecal indicator bacteria at Bolton Sewage Treatment Plant during summer weather conditions (Average water temperature 18.8°C)

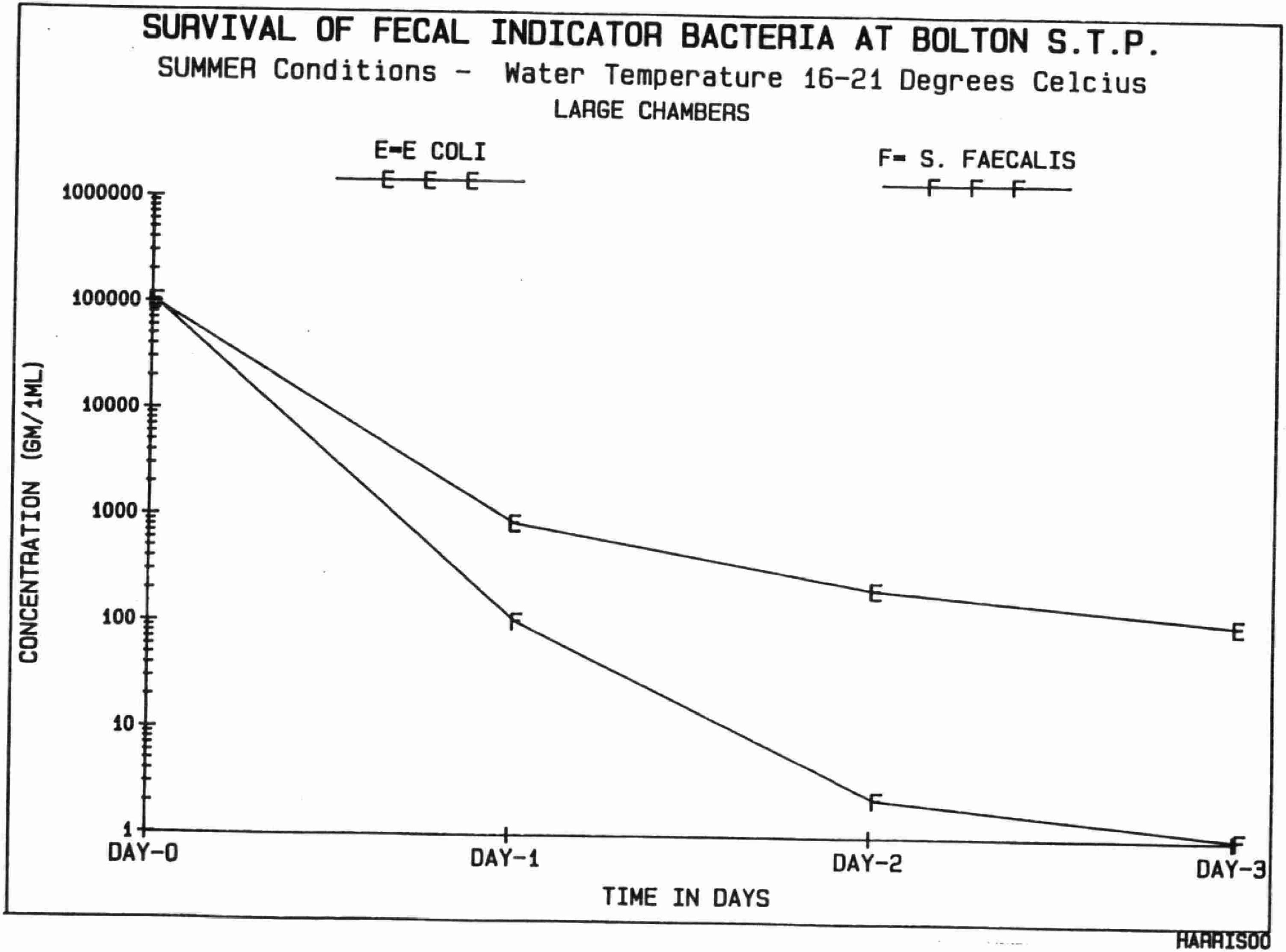
Bacterial Culture	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli (50 ml chamber)	1.6×10^5	3.0×10^2	1.7	<1
Escherichia coli (100 ml chamber)	1.01×10^5	8.5×10^2	2.1×10^2	1.03×10^2
Strep. faecalis (50 ml chamber)	3.0×10^5	3.0×10^3	10	2.6
Strep. faecalis (100 ml chamber)	1.0×10^5	1.0×10^2	2.2	<1

Table 42:

Percent die-off of fecal indicator bacteria at Bolton Sewage Treatment Plant during winter weather conditions (Average water temperature 3.25°C)

Bacterial Culture (50 ml chamber)	Concentration at Time 0 (CFU/ml)	Concentration at 24 hrs. (CFU/ml)	Concentration at 48 hrs. (CFU/ml)	Concentration at 72 hrs. (CFU/ml)
Escherichia coli	1.6×10^5	4.8×10^4	1.3×10^4	5.0×10^3
Strep. faecalis	2.0×10^5	9.3×10^4	2.7×10^4	1.4×10^4
Strep. faecium	2.0×10^5	3.4×10^4	4.1×10^4	3.8×10^4

Figure 68.



SURVIVAL OF FECAL INDICATOR BACTERIA AT BOLTON S.T.P.
SUMMER Conditions - Water Temperature 16-21 Degrees Celcius
LARGE CHAMBERS
E=E COLI
F= S. FAECALIS
1000000
100000
10000
1000
100
10
1
CONCENTRATION (GM/1ML)
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISOO

Figure 69:

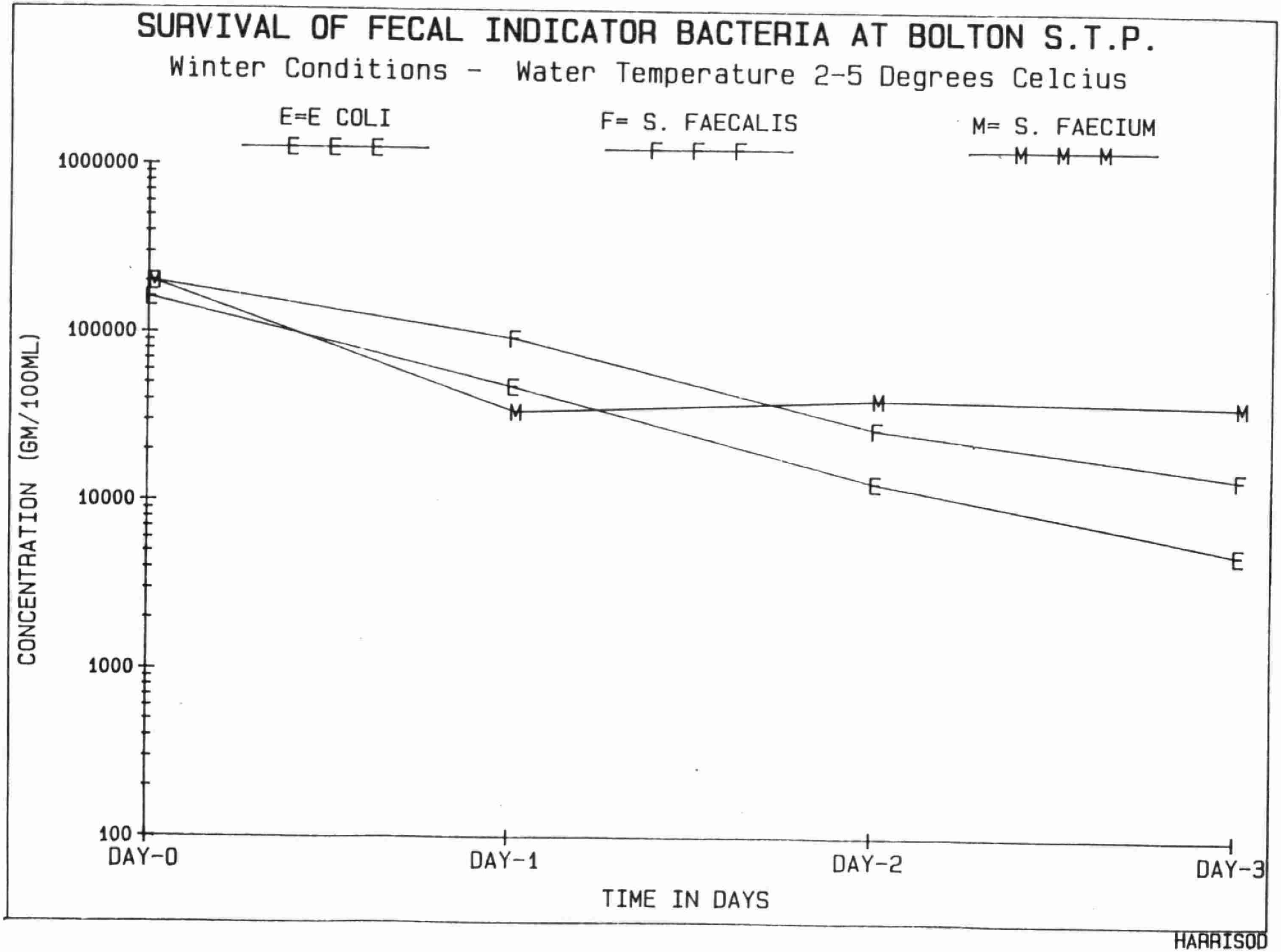

SURVIVAL OF FECAL INDICATOR BACTERIA AT BOLTON S.T.P.
Winter Conditions - Water Temperature 2-5 Degrees Celcius
E=E COLI
F= S. FAECALIS
M= S. FAECIUM
CONCENTRATION (GM/100ML)
1000000
100000
10000
1000
100
DAY-0
DAY-1
DAY-2
DAY-3
TIME IN DAYS
HARRISOD

Table 43

Overall location comparison with respect to the average increases in bacterial concentration and sediment weight during dry and intermediate weather (after sediment agitation) and from dry to wet weather, bacterial die-off rates and average stream flow.

Location and weather conditions	Sediment wt. (grms)	FC	EC	FS	Flow rate cms.	E. coli summer	E. coli winter	S. faecalis summer	S. faecalis winter	S. faecium summer	S. faecium winter
	Parameter per 100 mls sample					Percent die-off rate from 0 to 24, 48 and 72 hours					
Elhart Dr.											
Dry	0.013	341	203	136	1.660	24) 99.6	99.7	99.99	38.2	99.65	26.5
Int.	0.011	627	447	151	2.570	48) 99.99	99.9	100*	70.0	99.99	67.6
Dry to Wet**	0.019	3651	2337	1389	2.552	72) 100*	99.98	100	78.2	100*	91.0
Black Creek											
Dry	0.017	330	169	105	0.152	24) 80.2	93.8	85.0	56.3	(-)	55.7
Int.	0.013	613	509	288	0.221	48) 92.8	99.9	93.8	80.9	(-)	0
Dry to Wet	0.014	12738	7628	11226	0.284	72) 97.4	100	96.3	92.3	(-)	0
Emery Creek											
Dry	0.010	281	126	119	1.898	24) 98.3	88.7	99.9	(-)	96.1	(-)
Int.	0.006	418	156	457	2.557	48) 99.8	88.1	100	(-)	99.99	(-)
Dry to Wet	0.013	2076	1317	710	2.642	72) 97.6	98.2	-	(-)	100	(-)
James Gardens											
Dry	0.059	1074	801	121	2.593	24) 99.96	81.9	2.9	(-)	(-)	(-)
Int.	0.038	949	680	243	3.193	48) 99.98	84.4	84.7	(-)	(-)	(-)
Dry to Wet	0.010	2758	2181	1818	4.468	72) 100*	98.4	99.0	(-)	(-)	(-)
Teston Road											
Dry	0.036	695	660	73	0.046	24) 99.55	90.6	80.7	(-)	(-)	86.5
Int.	0.024	1776	1482	1313	0.098	48) 100*	91.5	99.90	(-)	(-)	62.0
Dry to Wet	0.001	3153	3062	685	0.055	72) 100*	92.5	99.98	(-)	(-)	74
Bolton											
Dry	0.031	191	178	52	1.273	24) 99.8	70.0	99.0	53.5	(-)	83.0
Int.	0.016	283	499	217	1.427	48) 100*	91.9	100*	86.5	(-)	79.5
Dry to Wet	-0.004	358	235	281	1.460	72) 100	96.9	100*	93.0	(-)	81.0

(-) No result due to chamber loss or breakage.

* Less than 10 bacteria present per ml.

** Change in flow from dry to wet - wet is not peak flow but based on flow at time of sampling.

studied, the small chamber is preferable and should be used for bacterial inter-comparison purposes.

The in-situ conditions existing during the winter studies (Fig. 69 and Table 42) e.g. colder temperatures, caused a significant increase in the ability of both E. coli and S. faecalis to survive exposure to the aquatic environment. S. faecalis die-off rates were again less than those of E. coli; however, S. faecium, which was also run, demonstrated the best overall ability to survive.

The relatively slower winter die-off rates would have the effect of increasing the zone of impact of pollution inputs. This was also noted at other sites such as James Garden and Teston Road.

SUMMARY

A comparison of the overall average increase in bacterial concentration and sediment weight after MSR during dry and intermediate weather conditions at the six locations is presented in Table 43. The increases in water column bacterial concentrations from dry to wet weather along with bacterial die-off and average flow rates at each location is also given.

The Effect of MSR and the Deposition Capacities of the Different Reaches of the River

Dry Weather

The greatest increases after MSR in both sediment weight, fecal coliform and E. coli levels during dry weather (Table 43) occur at James Gardens followed by Teston Road. The other locations in descending order are Elhart Drive, Black Creek, Emery Creek and Bolton. It would appear that a continuous input of bacterial contaminants can cause a noticeable increase in bacterial sediment contamination. Direct input of fecal material has by and large the greatest localized effect on sediment quality as evidence by the high sediment bacterial concentrations at James Gardens and Teston Road, from waterfowl and cattle, respectively. Both locations have higher levels of deposition as seen by the quantity of suspended sediment in the water column after MSR (Table 43). Environmental factors such as the shallowness of the water column at these two locations probably contribute to the accumulation of the large direct inputs of fecal matter.

The fact that James Gardens exhibits a greater dry weather potential for deposition and sediment quality impairment is possibly due to a number of factors such as the high upstream loadings, greater dry weather flow and the input of gull feces containing higher concentrations of fecal indicator bacteria (49, 50). Previous studies have examined the effects of waterfowl populations on bacterial water quality and have found that birds

do have a significant effect on surface water bacterial levels (51-54). In one study (55) it was found that high bacterial concentrations in surface waters at a large waterfowl refuge correlated directly with high sediment concentrations.

It is interesting to note however, that although the effect of sediment resuspension on water quality was greatest at James Gardens during dry weather, the impact of the pollution input on the water column before MSR was masked by the already existing high pollution loading in the area. Based upon water column sampling alone, the pollution input at this location might go undetected. This masking effect was also observed at other locations (i.e. Elhart Drive, Black Creek and Bolton). At Teston Road, and Emery Creek, the impact of the pollution inputs was quite noticeable in the water column before MSR possibly because of the lower upstream levels. As well, at Emery Creek the high loadings resulting from the greater flow in the creek (i.e. compared to flows from storm and combined sewer outfalls) would increase its impact on the water column. The impact of cattle contamination on surface waters has been reported to be quite dramatic causing considerable water quality deterioration (56-58).

Although there appears to be an increased level of deposition to the sediments at the Bolton sewage treatment plant, the bacterial concentrations in the sediments are the lowest exhibited at any of the six locations (Table 43). This was most

likely the result of a detrimental effect by the chlorinated sewage effluent.

The level of deposition at Black Creek was somewhat higher than at Elhart Drive, however, the bacterial response after MSR was not as great at Black Creek as at Elhart Drive, due to the fact that there was not a significant continuous dry weather input from the Hyde Avenue outfall. The sandy sediments at Black Creek may also have a less absorptive capacity.

There was somewhat less deposition occurring at Emery Creek compared to Elhart Drive. The concentrations of fecal coliforms and fecal streptococci per gram of sediment were higher at Emery Creek than at Elhart Drive, or Black Creek.

The level of E. coli per gram of sediment was also higher at Emery Creek than at Black Creek, but lower than at Elhart Drive. Thus it would appear that the lower bacterial response after MSR in Emery Creek was due to a lower rate of deposition than at Black Creek and a less "recent" fecal input than at Elhart Drive.

Wet Weather

During wet weather, the greatest increases in fecal coliform, E. coli and fecal streptococci levels were noted in Black Creek followed, by Teston Road (Table 43). The other locations in descending order of magnitude were: Elhart Drive, James Gardens, Emery Creek and Bolton. It is not surprising that Black Creek shows the greatest overall wet weather response in

bacterial contamination since the creek is impacted upon by a number of combined and storm sewers.

It has been noted that flow velocities of 0.61 m/sec. are sufficient to cause resuspension of clay and sand sediment particles (59). Although one would expect even higher velocities during wet weather in an area such as Black Creek due to its narrow channel and steep banks, the increase in suspended sediments from dry to wet weather were actually lower than during dry weather after MSR. This is due to the fact that the wet weather peaks were missed at Black Creek because of the study design (average wet weather flows recorded in Black Creek at Weston range from approximately 1 to 10 cms during the summer) and increased deposition resulting from flow decrease may have been occurring at the time of sampling. Wet weather peaks were probably missed at all of the locations as exhibited by the overall low increases in suspended sediment from dry to wet weather. However, it would appear that deposition was occurring more rapidly at some locations than at others due to differences in the hydrology and geomorphology of the various reaches of the river. For instance, at James Gardens, deposition may be occurring more rapidly than at Elhart Drive, possibly due to the shallowness of the water column. This would account for the lower FIB increases in the water column from dry to wet weather despite the fact that the FIB concentrations per gram of sediment were higher than at Elhart Drive.

<u>Intermediate Weather</u>

Mechanical sediment resuspension during intermediate weather conditions resulted in significant increases in water column FIB levels at all of the locations except Emery Creek (EC) and Bolton (FC). It is interesting to note that the <u>E. coli</u> increase after MSR was greater than the relative increase in FC at Bolton. This was due to the greater magnitude of increase in <u>E. coli</u> densities after MSR at the Bolton DN2 site from upstream and sanitary sewage effluent inputs and a possible input from a storm sewer at this location.

The greatest impact on water column FIB densities was exhibited at Teston Road during intermediate weather. This location on the east Humber River was situated in a valley and probably continues to receive a large amount of surface runoff during intermediate conditions. This runoff would of course contain fecal material from cattle that graze along the slopes.

The increase in suspended sediment levels after MSR were lower during intermediate weather than during dry weather at all the locations. This could possibly be the result of sediment erosion during storm events. There appeared to be a somewhat lower level of deposition at Teston Road compared to James Gardens; however, the sediments present at Teston Road exhibited a much greater level of contamination.

Bacterial Die-off

The die-off rates of E. coli during the summer varied from location to location, but were generally greater than 95% in 24 hrs. Only at one of the locations (Black Creek) did E. coli exhibit enhanced survival (80.2% die-off in 24 hrs.) and this, as previously mentioned, was most likely due to the increased nutrient input to Black Creek (60). Reduced sunlight penetration due to blockage by overhanging tree branches may have added to the increased survival effect. It is possible that the lower die-off rate of E. coli in Black Creek accounted in part for the increase in levels of this organisms after MSR during dry weather since there was very little dry weather pollution input from the Hyde Avenue outfall. At James Gardens, Teston Road, Elhart Drive and Emery Creek, the high E. coli die-off rates were off-set by the ongoing pollution input. Radiation of bacteria by sunlight (37) may be causing increased die-off rates at James Gardens and Teston Road because of the clearness and shallowness of the water column at these locations. However, sunlight would have less of an effect at Elhart Drive and Emery Creek due to poor penetration through cloudy water. A toxic effect from chemicals and heavy metals may have increased the die-off rate of E. coli in the Humber River at Emery Creek (34,35) since the creek is known to contain high levels of these pollutants (60). The high E. coli die-off rate at Bolton sewage treatment plant was undoubtedly due to the chlorinated effluent.

There appeared to be a leveling off effect on die-off rates between day 2 and 3 and die-off to extinction did not occur at any of the locations except Bolton. This would mean that the surviving bacteria are more hardy and could continue to persist in the environment for extended periods. Such a trend in die-off might also occur with enteric pathogenic bacteria as well.

In situ survival of other members of the coliform group (i.e. *Enterobacter* and *Klebsiella*) was not studied during the course of the investigation; however, previous studies have shown that these bacteria can persist in surface waters for longer periods than *E. coli* (41, 50). The ability of these species to utilize internal endogenous reserves may aid in increasing their survival in surface waters. The fact that some members of these species are encapsulated may also enhance their survival (41). Regrowth of coliforms in waters enriched by sewage, food processing plant and pulp and paper mill effluents has also been reported (61,62), as well as regrowth in sediments and soils (63, 64). Since a differential die-off rate occurs among members of the coliform group, the proportion of *E. coli* in fecal coliform populations will decrease with time. Thus, as previously mentioned, the *E. coli* to fecal coliform ratio may be a good indication of the age of the contamination.

Streptococcus faecalis tended to survive somewhat better during summer conditions except at Elhart Drive and Emery Creek where it declined more rapidly than *E. coli*. Dutka and Kwan (65) also found *E. coli* survival response to be greater than *S.*

faecalis in Lake Ontario waters. Streptococcus faecium exhibited a somewhat slower die-off rate than either S. faecalis or E. coli. This bacterium has been known to survive for more than 42 days in surface waters (42).

Extended survival rates of Enterococci (i.e. S. faecalis and S. faecium) may account for the decrease in FC/FS ratios in the Humber River and Black Creek during wet weather. It is possible that streptococci from older or distant inputs are surviving better in the sediments and are causing increases in water column levels when sediments are agitated during storm events. Additional streptococcal organisms from plant sources may also be washed into the river through storm runoff (66,67) thereby increasing the FS levels. Previous investigators have suggested that the FC/FS ratio should be used with caution because of the differential die-off rates of the two indicator groups and the effect of environmental factors which may alter their relationship possibly leading to erroneous interpretation of the ratios (13, 48, 60).

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APPENDIX A-1: Description and Use of Diffusion Chambers

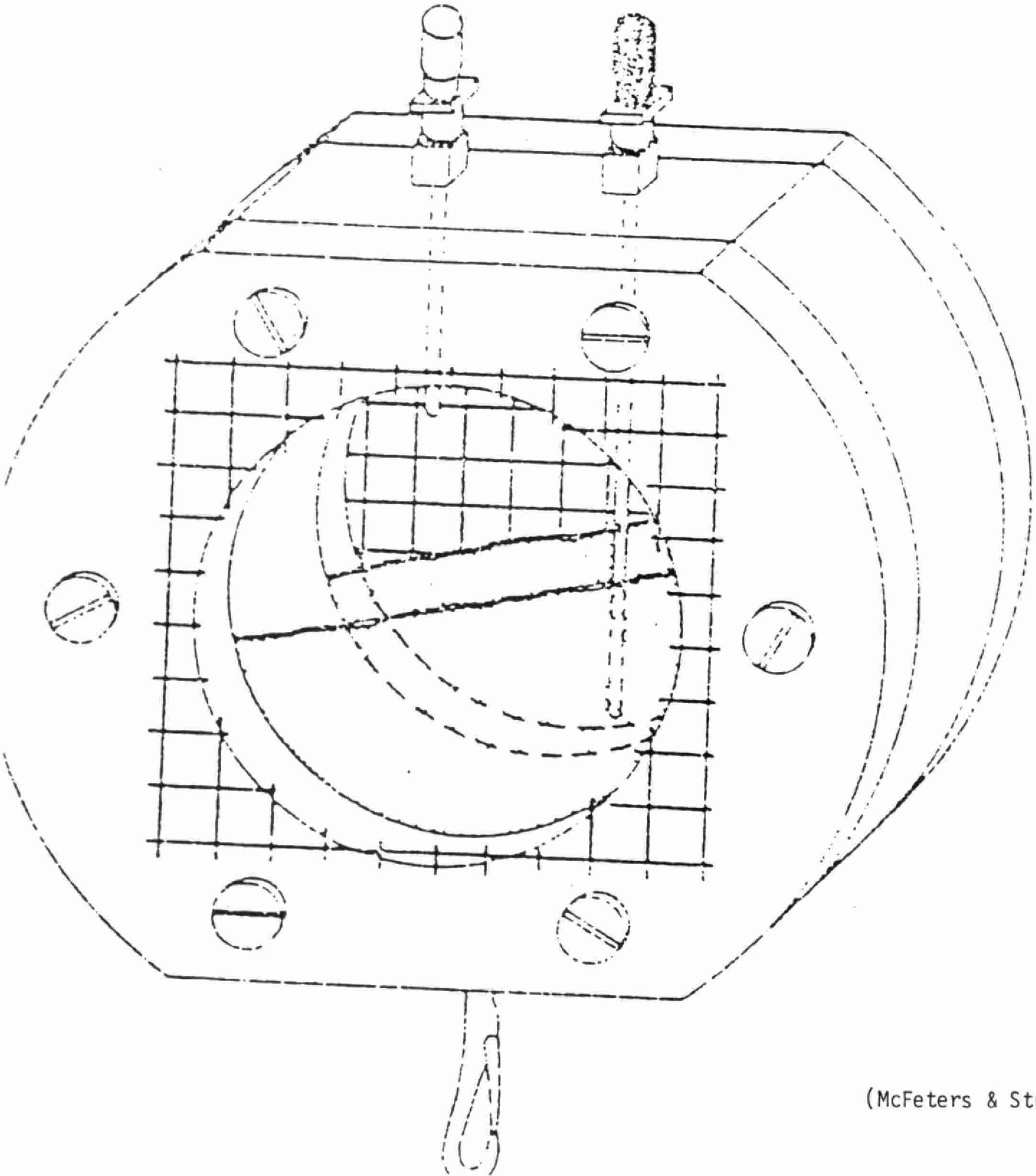
The 50 and 100 ml dialysis membrane diffusion chambers used in the survival studies were designed by McFeters and Stuart in 1972 (40). The chambers consist of a 3-part plexiglass-II cell with membrane filter sidewalls (Fig. 1). The filter sidewalls were made of a polycarbonate film with a pore size of 0.2 micrometers (Nucleopore) which allows for a maximum exchange between the environment and the inside of the chamber while retaining the pure culture of bacteria. The diameters of the membrane filters used for the 50 and 100 ml volume capacity chambers were 90 mm and 142 mm respectively.

Luer-lock syringe needle ports with metal caps facilitate sampling of the chambers. One of the syringe needles had a plastic (PVC) capillary tube attached so that the sample withdrawn was from the middle portion of the chamber.

The plexiglass cell and polycarbonate membrane were autoclaved separately for 10 min. and then assembled aseptically for use. Wing nut bolts were used to hold the assembled chamber together.

The chambers were inoculated with the pure bacterial culture (see Appendix A-2) using a sterile 50 ml luer-lock syringe. The chambers were filled through the port which had the attached capillary tube, however, both port caps were removed during the procedure to allow air to escape. The chambers can accommodate slightly more than the specified volume and should be filled to

Figure 1A DIALYSIS DIFFUSION CHAMBER



(McFeters & Stuart, 1972)

actual capacity. During the filling procedure, the chambers were partially submerged in a container of chilled receiving water.

The filled chambers were tightly capped and placed in small plastic receptacles containing chilled water from the test site. The sealed receptacles were placed into coolers containing ice packs and transported to location.

The chambers were sampled using 10 ml sterile plastic luer-lock syringes. The syringe was locked onto the port with the attached capillary tube and pumped 10 times to resuspend settled cells before removing the sample. Volume of approximately 12 mls were removed from the chambers and transported back to the laboratory in sterile screw capped test tubes stored on ice.

The advantages of using membrane diffusion chambers were that they better simulated the natural environments studied. The microorganisms were exposed in situ to many of the ambient physical and chemical factors that influence the nature microbial community. The high surface area to volume ratio and ease of sampling of diffusion chambers were also advantageous to in situ studies.

APPENDIX A-2: Preparation of Pure Bacterial Cultures for Use in Diffusion Chambers

Pure cultures of Escherichia coli, Klebsiella pneumoniae, Streptococcus faecalis, Streptococcus faecium and Streptococcus bovis were prepared by inoculating 5 mls of Brain-Heart infusion broth with a single colony from a pure culture of the bacterium

grown overnight on Brain-Heart infusion agar. The broth cultures were incubated for 16 hrs. at 35°C and then centrifuged at 3000 rpm for 15 minutes. The supernatant was removed and the cells resuspended in 5 mls of chilled gelatin phosphate buffer and re-centrifuged as above. After discarding the buffer supernatant, the cells were resuspended once again in 5 mls of sterile gelatin phosphate buffer and measured on a spectrophotometer at 660nm. If an optical density reading of 1.1 was obtained, the culture contained approximately 10^8 bacterial cells. Tenfold dilutions of the culture were made up to a 1 in 100,000,000 dilution of the original culture in 99 ml sterile phosphate buffered water blanks with the exception of the 1 in 10,000 ml dilution of the original culture which was prepared by transferring 10 mls of the 1 in 100 ml dilution to a flask containing 990 mls of chilled sterilized water from each of the test sites. The 1 in 10,000 ml dilution was used to fill the chambers so that the approximate cell density would between 10^4 to 10^5 organisms per ml as concentrations of greater than 10^6 organisms may produce a delayed die-off effect (40). The 1 in 100,000 ml to 1 in 100,000,000 ml dilutions were analyzed by membrane filtration and the membrane filters planted onto appropriate selective agar (i.e. m-TEC for <u>E. coli</u>). The media were incubated and subsequent colony counts obtained in order to determine the actual cell density of the original pure culture. Samples of the pure cultures removed from the chambers during the die-off study were also analyzed by membrane filtration in order to obtain comparable results.

<u>APPENDIX B</u>: **Particle sizing of Humber River and Black Creek suspended sediments.**

<u>APPENDIX B-1</u>: **Size fractions by weight of suspended sediment particles obtained before and after mechanical sediment resuspension at sampling locations on the Humber River and Black Creek.**

Table 1: Humber River at Elhart Drive Storm Sewer Outfall No. 250.

Table 2: Black Creek at Hyde Avenue Combined Sewer Outfall No. 159

Table 3: Humber River at the Mouth of Emery Creek.

Table 4: Humber River at James Gardens

Table 5: East Humber River at Teston Road

Table 6: Upper Humber River at Bolton Sewage Treatment Plant.

<u>APPENDIX B-2</u>: **Size fractioning by electron-microscopy examination of suspended sediment particles obtained before and after mechanical sediment resuspension and during storm events in the Humber River and Black Creek.**

Figure 1: Black Creek at the upstream site before and after sediment resuspension and at source after sediment resuspension.

Figure 2: Humber River at James Gardens source site before and after sediment resuspension.

Figure 3: Humber River during storm events.

Figure 4: Scanning electronmicrograph of suspended sediments in the Humber River at James Gardens source site before mechanical sediment resuspension.

Figure 5: Scanning electronmicrograph of suspended sediments in Black Creek upstream of the Hyde Avenue C.S.O. before mechanical sediment resuspension.

Figure 6: Scanning electronmicrograph of suspended sediments in Black Creek upstream of the Hyde Avenue C.S.O. before mechanical sediment resuspension.

Figure 7: Scanning electronmicrograph of suspended sediments in the Humber River at James Gardens source site after mechanical sediment resuspension.

Figure 8: Scanning electronmicrograph of suspended sediments in Black Creek at the Hyde Avenue C.S.O. (source site) after mechanical sediment resuspension.

Figure 9: Scanning electronmicrograph of suspended sediments in the Humber River during storm events (event 1).

Figure 10: Scanning electronmicrograph of suspended sediments in the Humber River during storm events (event 2).

<u>APPENDIX B-1</u>: Size Fractions by Weight of Suspended Sediment Particles Obtained before and after Mechanical Sediment Resuspensions at Sampling Locations on the Humber River and Black Creek.

Suspended sediment size fractioning by weight was performed on samples from the 6 study locations during the month of September. Tables 1 through 6 demonstrate the particle size fractions (by weight) present both before and after mechanical sediment resuspension at each of the sampling sites at the 6 locations. A description of the water column and bed sediments as well as a brief discussion of the results is presented along with each Table.

Although size fractioning by weight does not give an indication of the number of particles present within a specific size fraction, it does provide data on the relative proportions of different size particles (i.e. whether mainly smaller or larger sized particles are present). As well the data obtained can indicate changes in predominant size fractions between sites and whether the pollution inputs have an effect on sediment particle sizes.

At all of the locations, there was a trend towards a proportional recovery (by weight) of larger sized particles (i.e. 3.0 to > 12.0 µm) after sediment resuspension. However, at the source sites and to some extent at downstream 1, significant weights of smaller sized particles (i.e. 0.2 to 1.0 µm) were detected as well. The presence of these smaller sized particles

Table 1: **Suspended sediment size fractions by weight in the Humber River at Elhart Drive storm sewer outfall No. 250. Before and after mechanical sediment resuspension.**

Weight fraction per 100 mls suspended sediment/water sample at sites

Particle	Upstream		Source		Downstream I		Downstream II	
Size (um)	Before	After	Before	After	Before	After	Before	After
0.2	0.000	0.004	0.001	0.001	0.00	0.001	0.001	0.000
0.4	0.001	0.001	0.093	0.020	0.012	0.011	0.001	0.003
1.0	0.001	0.000	0.002	0.003	0.001	0.001	0.001	0.001
3.0	0.000	0.000	0.001	0.005	0.001	0.000	0.001	0.001
5.0	0.002	0.012	0.002	0.002	0.007	0.006	0.002	0.004
8.0	0.001	0.003	0.000	0.020	0.002	0.001	0.001	0.000
10.0	0.001	0.002	0.001	0.005	0.001	0.001	0.001	0.001
>12.0	0.007	0.014	0.001	0.003	0.003	0.005	0.002	0.012

Description of bed sediments at Elhart Drive Location

Sediments in the Humber River at Elhart Drive storm sewer outfall No. 250 appear to be composed of a fine sand and clay mixture. There is a large amount of suspended sediment in the water column before mechanical sediment resuspension (see before results at all sites) and sediment particle sizes vary over a wide range (i.e. from 0.2 um to >12.0 um) both before and after sediment resuspension.

Table 2: Suspended sediment size fractions by weight in Black Creek at Hyde Avenue combined sewer outfall No. 159 before and after sediment resuspension.

Weight fraction per 100 mls suspended sediment/water sample at sites

Particle Size (um)	Upstream Before	Upstream After	Source Before	Source After	Downstream I Before	Downstream I After	Downstream II Before	Downstream II After
0.2	0.000	0.000	0.000	0.002	0.000	0.00	0.000	0.000
0.4	0.000	0.000	0.004	0.005	0.000	0.001	0.002	0.000
1.0	0.000	0.000	0.002	0.001	0.003	0.002	0.000	0.004
3.0	0.000	0.001	0.000	0.002	0.002	0.001	0.000	0.002
5.0	0.002	0.003	0.001	0.002	0.001	0.001	0.002	0.002
8.0	0.000	0.000	0.001	0.002	0.002	0.003	0.000	0.000
10.0	0.001	0.008	0.000	0.001	0.001	0.002	0.004	0.006
12.0	0.006	0.010	0.001	0.015	0.002	0.012	0.001	0.010

Description of bed sediments at Black Creek location

Sediments in Black Creek at Hyde Avenue combined sewer outfall No. 159 appear to be composed of mainly sand with some fine organic material and clay intermixed at the source site. The water column is varily clear before sediment resuspension as evidenced by the lower weight recoveries of suspended sediments compared to the Elhart Drive location "before" weights. Mechanical sediment resuspension affected increases by weight in many of the size fractions. However, the greatest increase was usually obtained in the larger size fractions (eg. 12.0 um).

Table 3: **Suspended sediment size fractions by weight in the Humber River at Emery Creek before and after sediment resuspension**

Particle Size (um)	Upstream Before	Upstream After	Source Before	Source After	Downstream I Before	Downstream I After	Downstream II Before	Downstream II After
	Weight fraction per 100 mls suspended sediment/water sample at sites							
0.2	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000
0.4	0.000	0.000	0.000	0.040	0.001	0.773	0.000	0.003
1.0	0.002	0.001	0.000	0.001	0.001	0.001	0.013	0.021
3.0	0.001	0.002	0.001	0.042	0.001	0.000	0.001	0.003
5.0	0.001	0.007	0.004	0.005	0.001	0.001	0.000	0.005
8.0	0.000	0.003	0.003	0.000	0.000	0.011	0.005	0.000
10.0	0.000	0.004	0.000	0.001	0.000	0.000	0.006	0.008
>12.0	0.006	0.0113	0.011	0.080	0.005	0.081	0.007	0.042

Description of Bed Sediments at Emery Creek

Sediments in the Humber River at Emery Creek appear to be composed of a more coarse type of sand than at the Elhart Drive location. At the source downstream I site there is an intermixture of fine organic material probably due to inputs from the creek. The water column is somewhat less cloudy than at Elhart Drive. However, there is still a fair amount of suspended sediment in the water before sediment agitation. Resuspended sediments (after agitation) are composed of a wide range of particle sizes although at the upstream site there is a somewhat greater component of large size particles and at source and downstream I a substancial number of smaller particles.

Table 4: Suspended sediment size fractions by weight in the Humber River at James Gardens before and after sediment resuspension

Weight fraction per 100 mls suspended sediment/water sample at sites

Particle Size (um)	Upstream Before	Upstream After	Source Before	Source After	Downstream I Before	Downstream I After	Downstream II Before	Downstream II After
0.2	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.002
0.4	0.002	0.003	0.001	0.001	0.001	0.001	0.002	0.001
1.0	0.001	0.001	0.002	0.003	0.008	0.010	0.002	0.022
3.0	0.000	0.012	0.001	0.001	0.013	0.020.	0.002	0.001
5.0	0.002	0.004	0.002	0.004	0.010	0.0012	0.003	0.002
8.0	0.001	0.000	0.000	0.000	0.013	0.022	0.020	0.022
10.0	0.001	0.002	0.001	0.001	0.018	0.021	0.001	0.004
>12.0	0.002	0.016	0.000	0.004	0.004	0.008	0.007	0.011

Description of Sediment Bed at James Gardens

Sediments in the Humber River at James Gardens appear to be composed mainly of clay. There is a fine organic silt top layer at source possibly composed of bird fecal material. The water column is quite clear and shallow at upstream and source, but deeper and cloudy downstream. Sediment resuspension affects increases in both small and large particle size fractions at all of the sites.

Table 5: **Suspended sediment size fractions by weight in the East Humber River at Teston Road before and after sediment resuspension.**

Weight fraction per 100 mls suspended sediment/water sample at sites

Particle Size (um)	Upstream Before	Upstream After	Source Before	Source After	Downstream I Before	Downstream I After	Downstream II Before	Downstream II After
0.2	0.000	0.000	0.001	0.002	0.000	0.000	0.000	0.000
0.4	0.000	0.000	0.001	0.004	0.000	0.002	0.000	0.000
1.0	0.000	0.000	0.002	0.022	0.001	0.002	0.000	0.000
3.0	0.000	0.001	0.000	0.000	0.001	0.002	0.000	0.006
5.0	0.006	0.005	0.000	0.002	0.002	0.001	0.000	0.002
8.0	0.000	0.003	0.000	0.001	0.000	0.000	0.000	0.001
10.0	0.002	0.004	0.000	0.001	0.003	0.008	0.000	0.002
>12.0	0.005	0.019	0.001	0.010	0.002	0.013	0.001	0.013

Description of Bed Sediments at Teston Road

Sediments in the Humber River at Teston Road appear to be composed of coarse sand at the upstream and downstream sites and fine organic material at the source site due to the heavy input of feces from cows. The water column is quite clear and shallow at all of the sites. Sediment resuspension affects increases mainly in the larger size fractions both upstream and downstream. However, at the source site, increases in the smaller size fractions occur as well.

Table 6: **Suspended sediment size fractions by weight in the Upper Humber River at Bolton Sewage Treatment Plant before and after sediment agitation.**

Weight fraction per 100 mls suspended sediment/water sample at sites

Particle Size (um)	Upstream		Source		Downstream I		Downstream II	
	Before	After	Before	After	Before	After	Before	After
0.2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.4	0.000	0.001	0.002	0.003	0.002	0.001	0.000	0.000
1.0	0.000	0.000	0.000	0.002	0.001	0.000	0.001	0.000
3.0	0.000	0.003	0.000	0.005	0.001	0.000	0.001	0.002
5.0	0.002	0.001	0.000	0.000	0.000	0.001	0.002	0.001
8.0	0.003	0.004	0.001	0.005	0.000	0.004	0.000	0.007
10.0	0.000	0.000	0.000	0.004	0.002	0.006	0.000	0.004
>12.0	0.005	0.023	0.004	0.008	0.004	0.010	0.004	0.011

Description of Bed Sediments at Bolton Sewage Treatment Plant

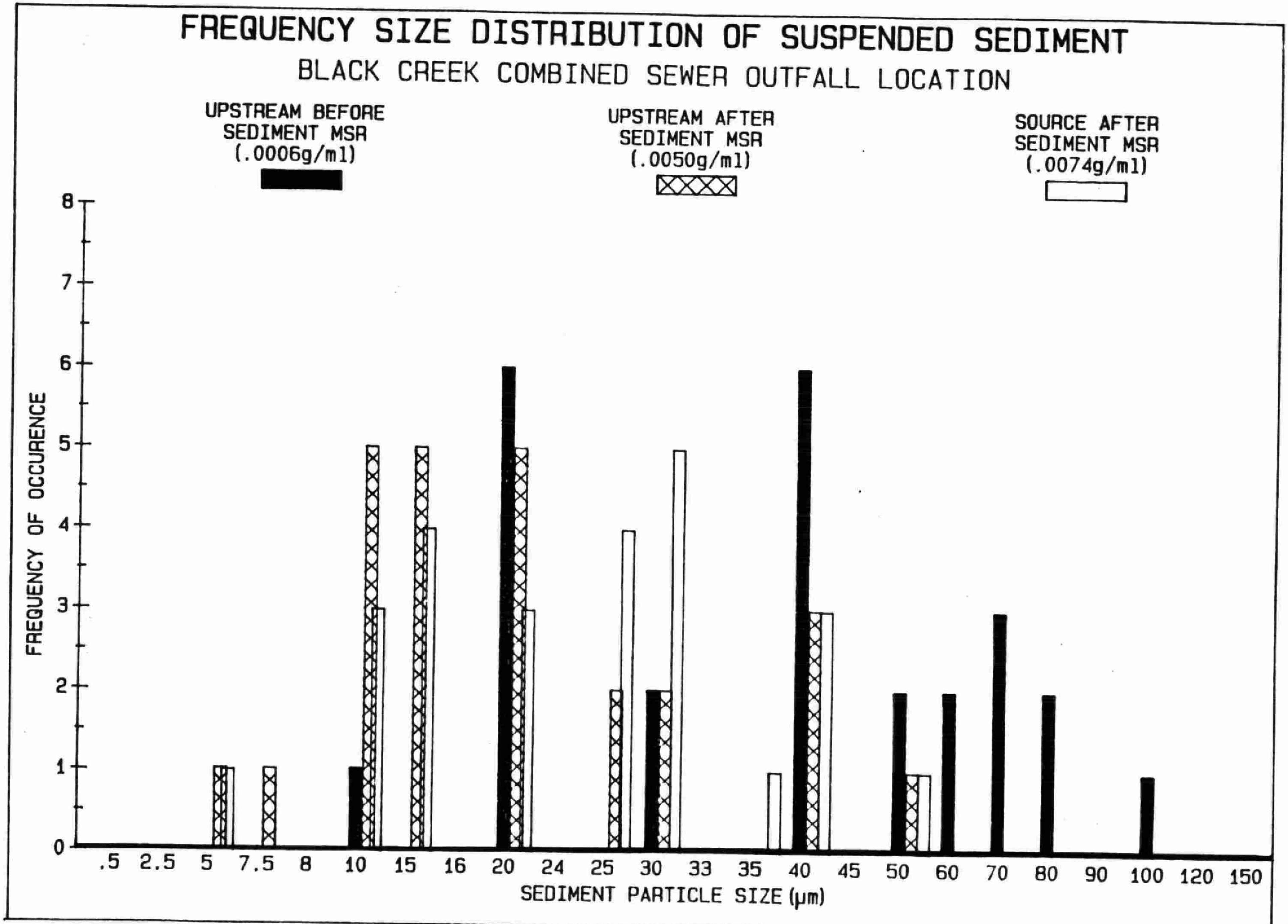
Sediments in the Humber River at Bolton Sewage treatment plant appear to be composed of coarse and especially at the upstream and downstream sites. The water column is clear before sediment agitation. However, there appears to be somewhat more suspended sediment in the water at upstream site. Sediment resuspension causes increases (by weight) to occur in the larger size fractions at all sites and in some of the small size fractions at source. This may be attributed to an input of fine particles the chlorinated effluent.

may be related to pollution inputs at source and to transport downstream.

APPENDIX B-2: Size Fractioning by Electronmicroscopic Examination of Suspended Sediment Particles Obtained before and after Mechanical Sediment Resuspension and During Storm Events in the Humber River and Black Creek.

Sediment size fractioning by electronmicroscopic examination was performed on samples from selected locations during the month of May 1986. This procedure determines the frequency of occurrence of particles within a specific size fraction. Figures 1 and 2 show the frequency of occurrence and the size fractions of suspended sediment particles obtained from the James Gardens and Black Creek locations before and after sediment resuspension during dry weather. Figure 3 gives the frequency of occurrence and size fraction of suspended sediments obtained from the Humber River during storm events. A comparison of the suspended sediments obtained after mechanical sediment resuspension during dry weather to those obtained during storms shows that similar particle sizes can be suspended during both processes. It is interesting to note that sediment agitation causes a shift in the frequency of occurrence towards smaller particles at both the James Gardens and Black Creek location. As well, the sediments at the Black Creek location are composed of larger sized particles than at James Gardens. This is due to the type of

Figure 1B: Black Creek at Upstream Site Before and After Sediment Resuspension and at Source After Sediment Resuspension.



HARRIS-BF

Figure 2: Humber River at James Gardens Source Site Before and After Sediment Resuspension.

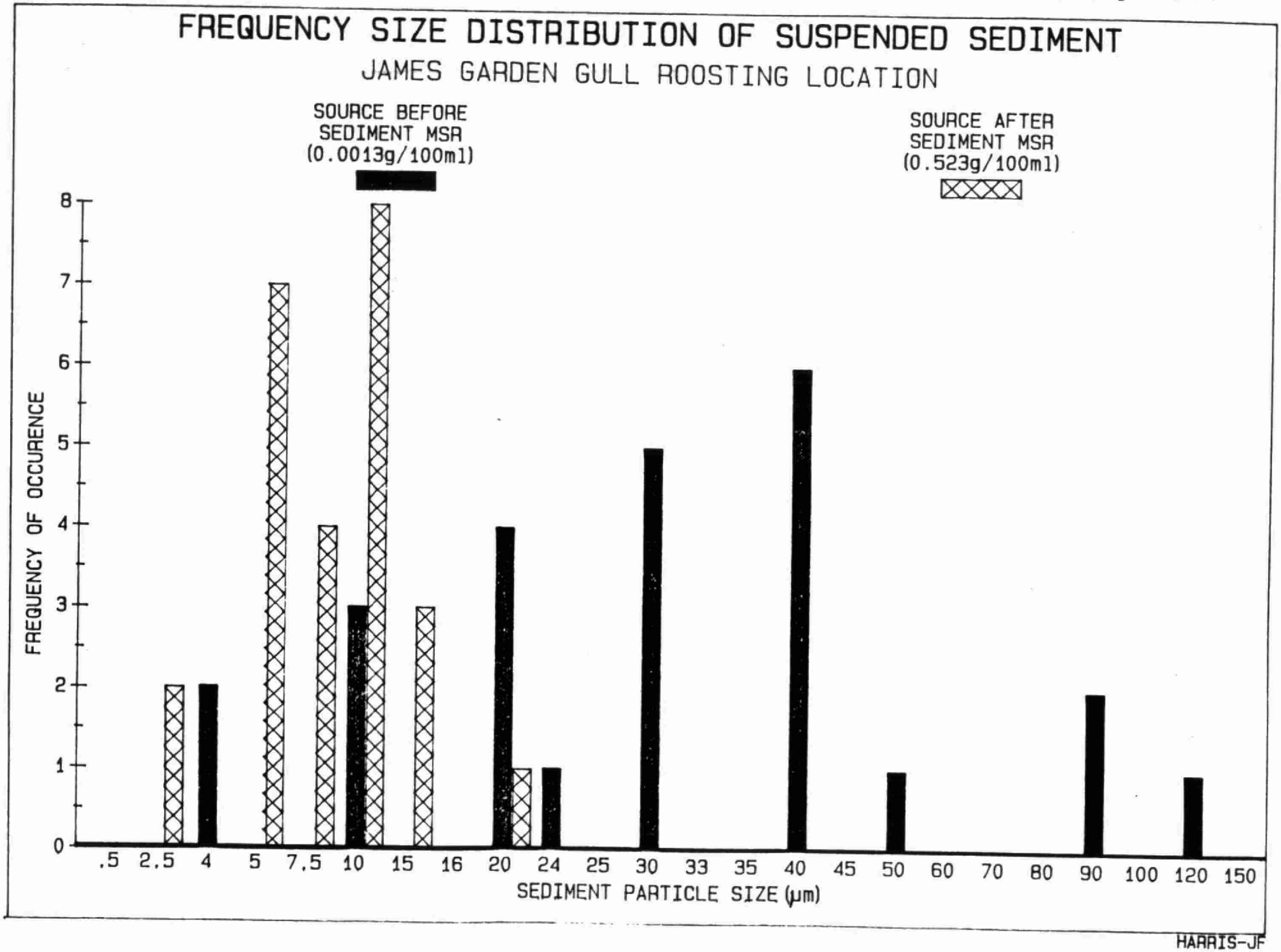
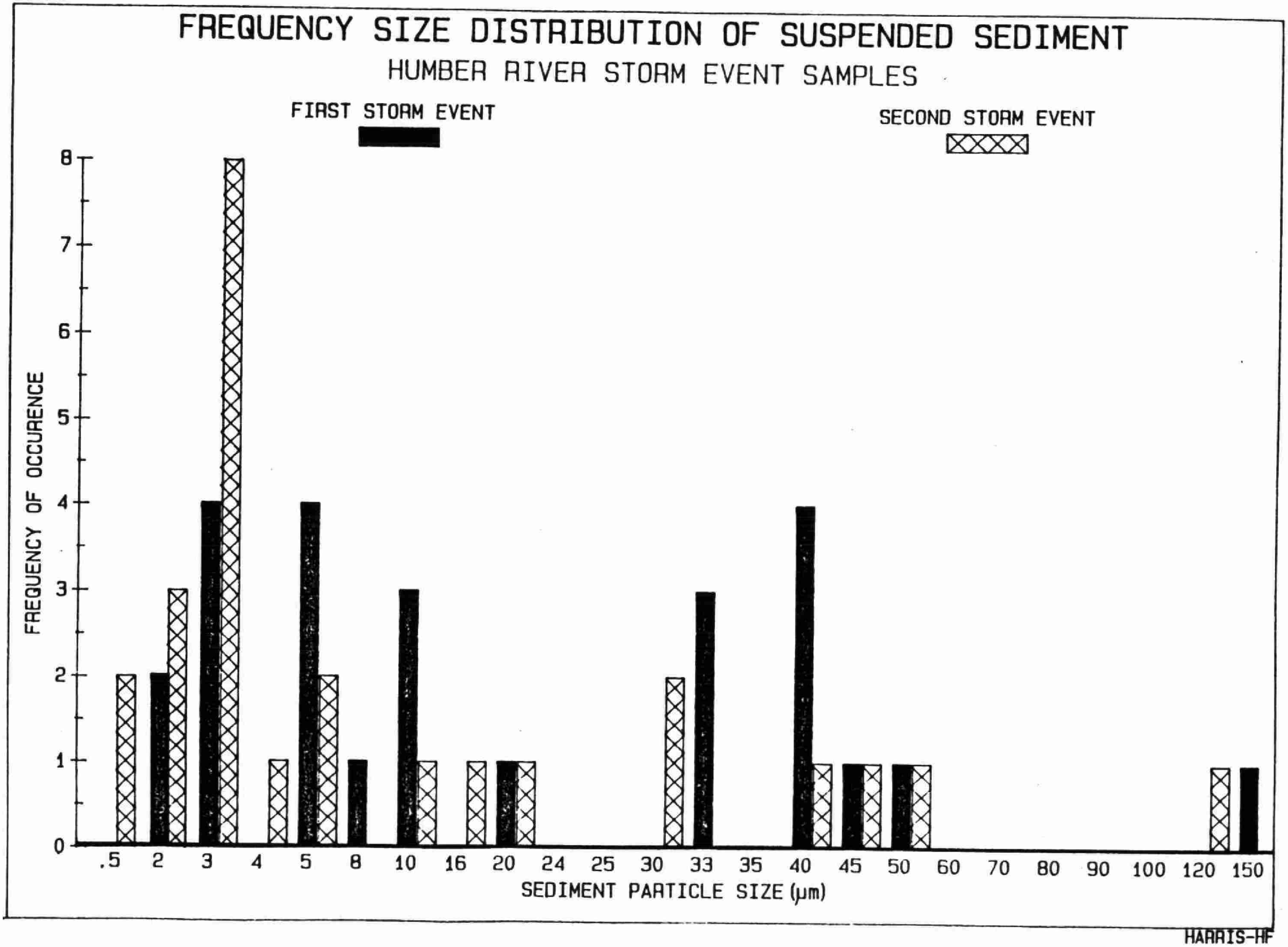


Figure 3: Humber River During Storm Events.



sediment at the Black Creek location (i.e. sand as compared to clay at James Gardens).

Figures 4 to 10 are scanning electronmicrographs of suspended sediment particles before and after sediment agitation at the above two locations and in the Humber River during storm events. The micrographs also show that sediment particles suspended in the water column under both conditions are of similar sizes. However, the density of suspended sediments is greater during storm events. Smaller particles in the Humber River at James Gardens (Fig. 7) after sediment agitation in comparison to those in Black Creek is again evident (Fig. 8).

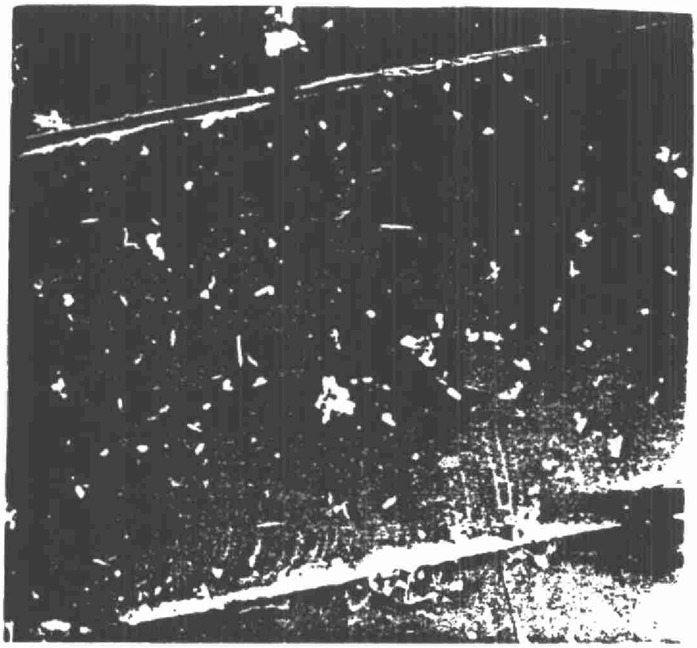


Fig.4. Scanning Electronmicrograph of Sediments in the Humber River at James Gardens Source Site Before Mechanical Sediment Resuspension.

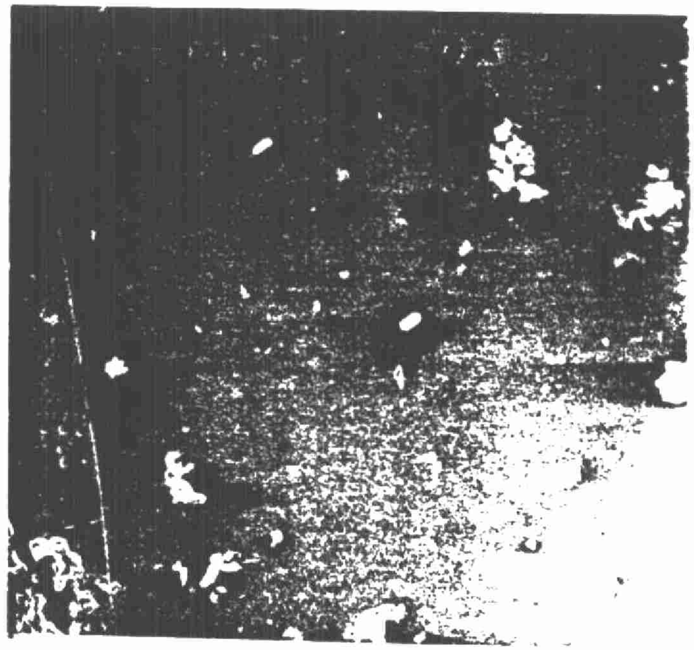


Fig.5. Scanning Electronmicrograph of Suspended Sediments in Black Creek Upstream of the Hyde Avenue, C.S.O. Before Mechanical Sediment Resuspension.

Fig.6. Scanning Electronmicrograph of Suspended Sediments in Black Creek Upstream of the Hyde Ave. C.S.O. After Mechanical Sediment Resuspension.

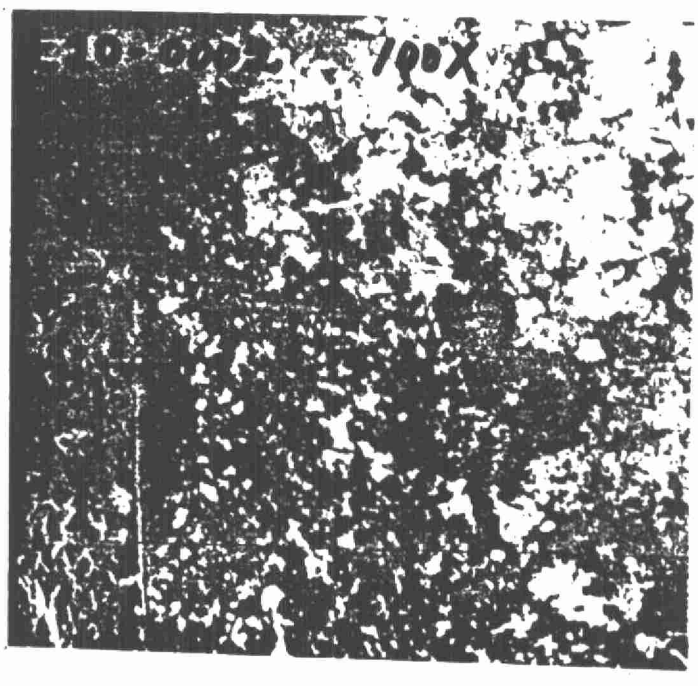


Fig.7. Scanning Electronmicrograph of Suspended Sediments in the Humber River at James Gardens Source Site After Mechanical Sediment Resuspension.

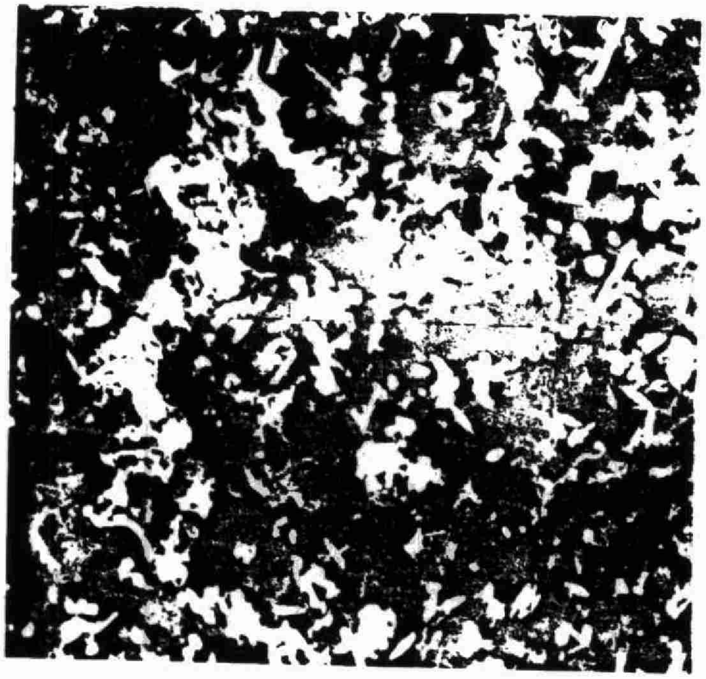


Fig. 8. Scanning Electronmicrograph of Suspended Sediments in Black Creek at the Hyde Ave. C.S.O. (source site) After Mechanical Sediment Resuspension.

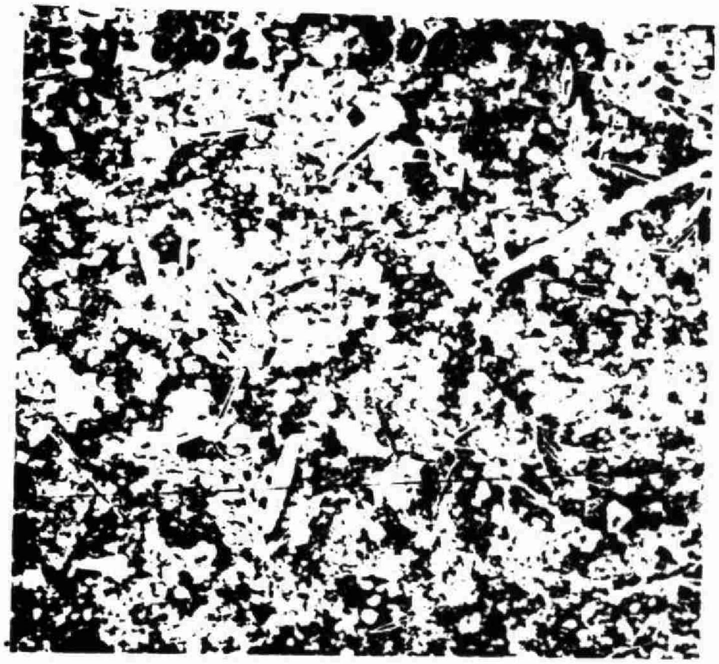


Fig. 9. Scanning Electronmicrograph of Suspended Sediments in the Humber River During Storm Events (Event 1).

Fig. 10. Scanning Electronmicrograph of Suspended Sediments in the Humber River During storm Events (Event 2).

APPENDIX C-2: Scheme for the Identification of Streptococcus Isolates Picked from m-Enterococcus or other similar Agars.

1. Pick isolated colonies from m-Enterococcus or other similar agar.
2. Transfer the growth to blood agar (5% rabbit's blood) and streak out for isolated colonies. Incubate the blood plates at 35^{o}C for 24 hours.
3. Examine incubated blood plates for purity and growth of the culture. Select one isolated colony from pure cultures only and prepare a reservoir of growth on Brain-Heart Infusion agar (BHI). Incubate the BHI plates at 35^{o} for 24 hours.
4. After incubation, use reservoirs of growth on BHI agar to check the Gram reaction (3% KOH method) and catalase reaction of the isolate.
5. If the isolate is Gram positive, catalase negative, then use the growth on BHI agar to inoculate the following physiological tests:
   a) Bile Esculin Agar
   b) Todd Hewitt Broth for growth at 10^{o}C
   c) Todd Hewitt Broth for growth at 45^{o}C
   d) 6.5% NaCl (in Heart Infusion Broth)
   e) Thornley's Arginine dihydrolase medium
   f) 2% soluble starch (in blood agar base)
   g) Tellurite Agar (0.04% Potassium Tellurite)
   h) 1.1% Arabinose (in Heart Infusion Broth)
   i) Gelatin (12% in Heart Infusion Broth)

j) Pyruvate broth

k) 1% Mannitol (in Heart Infusion Broth)

l) 1% Lactose (in Heart Infusion Broth)

m) 1% Sorbose (in Heart Infusion Broth)

n) Methylene Blue Milk (0.1% Methylene Blue in Skim Milk Broth)

The above series of tests will allow for separation of Enterococcus species from other faecal streptococci and from non-faecal streptococci. (See Table 1) Potential S. bovis, S. equinus and S. avium isolates must be tested serologically for the group D Antigen (see Serological Testing Method) before their identification can be confirmed, since they show biochemical reactions similar to the Viridans streptococci group. Variants of S. faecalis must be tested for their haemolysis reactions under anaerobic conditions on 5% rabbit's blood.

Streptococcus - Serological Grouping

Principle of Test:

The majority of streptococcus species possess group specific antigens which are usually carbohydrate structural components of the cell wall. These antigens can be extracted in soluble form and identified by precipitation reactions with homologous antisera. There are a number of ways to extract these antigens from the cell wall including:

1. Hot HCL extraction
2. Hot formamide extraction

Table 1

Some physiological reactions of the fecal streptococci
and some physiologically similar viridans streptococci
and aerococci useful for differentiation

Group	Organism	Bile Esculin	Growth 10°C	Growth 45°C	Growth 6.5% NaCl	Arginine	Starch	Tellurite	Arabinose	Gelatin	Tetrazolium	Haemolysis	Yellow Pigment	Methylene Blue Milk	Pyruvate	Mannitol	Lactose	Sorbose	Serogroup
FECAL STREPTOCOCCI / ENTEROCOCCI	S.faecalis	+	+	+	+	+	-/+	+	-	-	+	d/β	-	+	+	+	+	-	D
FECAL STREPTOCOCCI / ENTEROCOCCI	S.faecalis v.liquefaciens	+	+	+	+	+	-	+	-	+	+	d/β	-	+	+	+	+	-	D
FECAL STREPTOCOCCI / ENTEROCOCCI	S.faecalis v.zymogenes	+	+	+	+	+	-	+	-	v	+	β	-	+	+	+	+	-	D
FECAL STREPTOCOCCI / ENTEROCOCCI	S.faecium	+	+	+	+	+	-	-	+	-	-		-	+	-	+	+	-	D
FECAL STREPTOCOCCI / ENTEROCOCCI	S.faecium v.casseliflavus	+	+	+	+	+	-	v	+	-	v		+	+	-	+	+	-	D
FECAL STREPTOCOCCI / ENTEROCOCCI	S.durans	+	+	+	+	+	-	-	-	-	-		-	+	-	-	+	-	D
FECAL STREPTOCOCCI / ENTEROCOCCI	S.avium	+	+	+	+	-	-	-	+	-	v		-	-	+	+	+	+	Q/D
FECAL STREPTOCOCCI	S.bovis	+	-	+	-	-	+	-	-	-	v		-	v	-	+	+	-	D
FECAL STREPTOCOCCI	S.bovis variant	+	-	+	-	-	-	-	-	-	v		-	v	-	-	+	-	D
FECAL STREPTOCOCCI	S.equinus	+	-	+	-	-	-	-	-	-	-		-	-	-	-	-	-	D
VIRIDANS	S.mutans	-/+	-	+/-	-	-	-									+	+		E/NG
VIRIDANS	S.mg intermedius	-/+	-	-/+	-	+/-	-/+									-	+		F/NG
VIRIDANS	S. salivarius	($\bar{d}$)	-/+	+/-	-	-	-									-	+		K/NG
VIRIDANS	S.sanguis I	($\bar{d}$)	-	+/-	-	+/-	+/-									-	+		F/NG
	Aerococcus sp.	+/-	+	-	+	-													

v = variable   d= some may differ   NG - non-groupable

NOTE: 1) some S.bovis (starch -ve) variants cannot be distinguished from certain viridans streptococci (i.e. S.MG intermedius and S.sanguis I) except by serology.

2) The above reaction patterns are the most common variants for any particular test may occur.

3. Autoclave extraction
4. Sonication and
5. Enzyme extraction.

Each extraction method has certain advantages and disadvantages. Generally the autoclave extraction method and the enzyme extraction method are simple yet reliable procedures for all groups including group D. Some group D streptococcus species (i.e. S. bovis, S. equinus and S. avium), however, contain relatively small amounts of this antigen and these may require more severe extraction procedures (i.e. sonication).

The antigen antisera precipitation reactions can be performed in various ways including:

1. Capillary precipitin test
2. Slide agglutination reaction
3. Electrophoretic methods.

Probably the simplest method to employ is the slide agglutination procedure whereby group-specific antibody coated latex particles are reacted with the antigen extract.

There are commercially prepared kits available which provide the enzyme for an enzyme extraction, a reaction slide and antibody coated latex particles for various serogroups (generally groups A,B,C,D,F and G). These latex particles can also be reacted with extract from any other extraction procedure.

Methods

Enzyme Extraction: Latex Agglutination (commercially avail. kit)

1. Quality control - the kit contains a vial of polyvalent antisera. Mix one drop of each latex compound into one drop of antisera to ensure that each latex compound reacts appropriately.
2. Rehydrate the lyophilized extraction enzyme.
3. Cells for the extraction procedure for the unknowns can be taken from a plate or broth culture.
   a) Plate - sweep a light loopful of growth from a 24 hr. blood plate and emulsify in 0.4 ml extraction enzyme.
   b) Broth - take one drop of a 24 hr. Brain heart infusion + 1% dextrose broth culture and add to 0.4 ml extraction enzyme.
4. Incubate the extraction enzyme cell mixture one hour at 37°C (water bath).
5. Dispense one drop of the appropriate latex per corresponding circle on the agglutination slide.
6. Add one drop of the incubated extract to each latex drop.
7. Mix until smooth and milky using a separate applicator stick for each circle.
8. Gently rock and rotate the slide until a reaction occurs in one of the circles (usually within one to two minutes). A positive agglutination is noted when the smooth milky emulsion changes to granular.
9. Record which group antigen if any is present.

<u>Autoclave Extraction of Group Antigen</u>

1. Grow pure isolate in Brain heart infusion broth plus 1% dextrose (final concentration) 24 hr., 35°C, - 16 x 100 mm screw cap tube, 8 mL broth per tube (tube must be suitable for centrifugation).
2. After incubation centrifuge broth culture at 3000 rpm, 10 min. to pack cells.
3. Decant liquid into a disinfectant and retain cells.
4. Add approximately 5 mL of aqueous 0.85% NaCl solution (physiological saline) to the tube and resuspend cells.
5. Centrifuge the cells a second time at 3000 rpm, 10 min. to pack cells.
6. Decant liquid into a disinfectant and retain cells.
7. Add 2-3 mL physiological saline to the tube and resuspend the cells.
8. Autoclave the tube 15 min., 15 psi (121°C).
9. After autoclaving, allow to cool and centrifuge the tube at 3000 rpm, 5 min. to pack cells.
10. Once the cells are packed the liquid (extract) phase can be used to perform the serological testing (see latex method).

<u>APPENDIX C-3</u>: Reference used to develop scheme for fecal streptococcus identification

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APPENDIX D: Detailed Description of Project Results

Elhart Drive (Storm Sewer) - **Sediment Resuspension** (Figure 2 - 8, Table 1)

The agitation of sediment (SED) at the Elhart Drive storm sewer site caused an increase in SED concentration at all sites particularly at, and just below the source (Fig. 2). The levels of suspended sediment (S.SED) in the water column during wet weather was higher than that caused by mechanical agitation except at the first downstream site. The water SED concentrations during intermediate conditions fell between those under wet and dry conditions and were lower than levels created by agitation.

The source input contains S.SED under dry and wet weather but was below detection limits during intermediate conditions. When detected the concentrations were lower than in the water column.

The mechanical resuspension of SED increased concentrations of fecal indicator bacteria (FIB) in the water column noticeably with the exception of the upstream (UP) site [fecal coliforms (FC), E. coli (EC) and P. aeruginosa (PSA)] and the first downstream site (DN1) [EC and Enterococci (ENT)]. Fecal streptococci (FS) concentrations were similar at each site while the other FIB exhibited the greatest increase at the source.

The effect of a storm event was quite dramatic with the FIB water densities increasing by an order of magnitude. In most cases the highest concentrations were noted at the source with lower levels downstream. PSA densities were highest at DN1 and the EC and ENT showed an increase between DN1 and the second downstream station (DN2).

During intermediate conditions (24-48 hrs. after end of storm) FIB concentrations remained elevated above dry weather levels both before and after mechanical SED resuspension (MSR). No consistency between patterns of changes in FIB levels were observed. The application of MSR still resulted in increased FIB densities in the water column (Table 1).

The concentrations of FIB in the storm sewer outfall (SSO) flow were higher than those observed in the river; FC, EC and ENT in the SSO effluent were lowest in concentration during intermediate conditions. FC and EC exhibited the highest levels during dry weather while ENT was slightly higher under wet weather conditions than dry.

FC/FS

The FC/FS ratios showed little change following MSR at the two downstream stations, however at source the FC/FS ratio increased from 4.5 to 8.7 and upstream it decreased from 4.7 to 2.8. The highest FC/FS ratio was at source following MSR. Wet weather FC/FS ratios showed little change between sites and were similar to dry weather upstream levels (before MSR). The ratios

observed during intermediate conditions were somewhat lower than the dry weather (before MSR) FC/FS ratios at UP and source but increased above these levels at the two downstream sites.

<u>Post-Rainfall Bacterial (EC/FC) Quality</u> (Table 2)

The initial instream response following the high EC and FC wet weather concentrations (day 0) was a rapid decrease followed by a smaller increase on days 3 and/or 4. The SSO EC and FC concentrations were also highest during day 0, but otherwise their levels showed variability over the following four days. With four exceptions (UP/day 1 before MSR, DN1/day 0 before MSR, DN2/ day 2 after MSR and SSO/day 2 the EC/FC ratio was 0.6 or above. As the antecedent period increased the EC/FC ratio tended to increase following MSR at UP and source while decreasing at DN2.

<u>Natural Environmental Phenomena and Bacterial Concentrations</u> (Figures 9A - 9B)

The data presented in figures 9A and 9B was obtained on site at the same time as the SED agitation work. The SED and bacterial concentrations were from the source site before MSR, while flows were obtained from a gauge positioned upstream. (<u>Note</u>: the staff gauge was not in place prior to June 5th).

Extensive variability was seen with all three parameters which was expected because of the number of factors affecting them. Flow (CMS) was the only parameter which was relatively constant during two survey periods (July 2nd - 4th and July 29th-

31st). Only during the June 17th - 19th survey did the daily changes in all the parameters follow like patterns. There also may have been some similarity in change between SED concentration and flow during the first survey as flow was decreasing in the main Humber during this period (see Discussion).

The correlation coefficients based on regression analyses between E. coli, FC, SED weight and flow during dry weather are shown in Tables 3 and 4. Both tables are divided into three parts.

Table 3 contains results from the comparison of SED weight at different sites and with FC and EC at all sites. A comparison with flow rate is shown at the bottom. Good positive correlations were obtained in all SED to SED comparisons except between water sediment content at UP and DN1. Lower values were obtained in the comparisons with the bacterial parameters. Poor correlations were obtained between SED and FC for all DN1 SED comparisons and between FC/SED DN2 levels. The same is true of the E. coli comparisons plus EC at DN1 and SED at UP and source.

Table 4 lists the correlation coefficients from regression analysis between FC, EC and Flow at all sites. There is a strong positive correlation when comparisons are made between parameters at the same site. The correlations tend to remain strong at adjacent sites but to decrease with distance. Correlation coefficients just below .5 were obtained between the E. coli levels at UP and DN2.

The only good correlation with flow rate was between FC at source. All other correlation coefficients were well below $\pm$ 0.5.

Streptococcus Populations (Table 5)

Dry Weather

S. faecium var casseliflavus was the largest single streptococcus type isolated at all sites both before and after MSR. The resuspension of sediment, however, caused a drop in the percentage isolation of this bacteria and also S. durans. S. faecalis var liquefaciens isolation was always increased as a result of MSR.

Wet Weather

Upstream S. faecalis var liquefaciens was isolated at a higher percentage level than during dry weather while S. faecium var faecium formed a much lower proportion of the population than during dry weather. At source and DN1 the most frequently recovered species was S. faecium var faecium rather than S. faecium var casseliflavus. S. durans was still second in percent recovery but was isolated in higher proportions.

Bacterial Survival - Summer Conditions (Figure 11 and Table 6)

At this site S. faecalis var liquefaciens died off more rapidly than either E. coli or S. faecium var faecium and could not be isolated from the chambers on the third day in situ.

Initially S. faecium decreased at a more rapid rate than E. coli (Day 1). However on day 2 they were at approximately the same level and by day 3 E. coli was slightly lower.

Winter Conditions (Figure 12 and Table 7)

The two streptococci species decreased very slowly and at approximately the same rate. Their overall decline was considerably less than during the summer. E. coli declined more rapidly between day 0 and 1 than during the summer. However, the rate of decrease slowed down after the first day *in situ* and was slower than the summer rate between day 1 and 3. The net effect was a decrease of about two orders of magnitude less than during the summer.

Black Creek (Combined Sewer) - Sediment Resuspension (Figures 13 -19, Table 8)

The water column concentration of S.SED (Fig. 13) during dry weather before MSR decreased from UP to DN1 and then increased at DN2 to a level intermediate between UP and DN1. MSR increased concentrations of S.SED at all sites particularly at DN1 which now had the highest level of S.SED.

Wet weather S.SED was slightly higher than dry weather MSR results at UP and source but lower at DN1 and approximately the same at DN2.

During intermediate conditions the resuspended SED levels were between wet and dry levels at UP but could not be detected

at the other sites. MSR (Table 8) increased S.SED levels to approximately wet weather concentrations, except at DN2 where it went to only one-half the wet weather level. CSO flow (wet weather only) contained S.SED at a concentration similar to those instream during wet weather.

Little or no increase in FIB concentrations were affected by MSR except for FC at UP, FS and ENT at source and DN2 and PSA at source. Wet weather concentrations varied little from upstream to downstream but were significantly higher than the dry weather results. FC and EC show a slight decrease downstream while PSA had a small increase. FS and ENT showed no particular trend.

Concentrations of FIB during intermediate conditions have a tendency to be lower than those existing during dry weather conditions except for FS at source and DN2 and PSA at all locations. The highest concentrations were at source except for FS for which DN2 had the highest levels. MSR during intermediate conditions increased most FIB levels above those obtained during dry weather. The exceptions were FC and EC at DN1 and DN2, FC at source and FS at DN2. Except for the above levels and ENT at DN2, the intermediate MSR concentrations were also higher than those obtained after MSR during dry weather. FIB concentrations in the CSO during wet weather storm events were roughly an order of magnitude higher for FS, ENT and PSA and two orders higher for FC and EC than those observed instream at the source.

<u>FC/FS</u>

The FC/FS ratios (Figure 19) at Black Creek changed little from site to site and showed no obvious trends before or after MSR. There was no MSR effect on FC/FS at UP but it caused a decrease at source and DN2 and an increase at DN1. Wet weather FC/FS values were lower than either dry weather results and showed a tendency to decrease downstream. Intermediate FC/FS ratios fell between dry weather and wet weather ratios appearing to be more influenced by wet weather conditions at UP and DN2. The CSO FC/FS value (wet weather) was about an order of magnitude higher than that found instream during wet and dry weather.

<u>Post-Rainfall Bacterial (EC/FC) Quality</u> (Table 9)

The EC and FC concentrations dropped considerably between day 0 (rainfall and the first day following rain (day 1). The levels continued to fluctuate following day 1, but not to the same extent.

There were four instances when the EC/FC ratio was below 0.6, these were at UP on day 2, 3 and 4 and DN2 on day 4 all following MSR. Thus there appeared to be a trend to lower EC/FC ratios following MSR at UP and DN2. However, at source the ratio did not change.

Natural Environmental Phenomena and Bacterial Concentrations

(Figures 20 and 21)

Flow measurements were only available at this site up to July 12/85, due to the destruction of the staff gauge.

The source degree of variability was seen here as at the previous site and the only survey in which all these parameters followed the same pattern of change in magnitude was July 2nd to 4th, 1985. During the first survey (for June 3-5) SED concentration and flow followed similar patterns of change and during the July 15th to 17th survey SED and FIB concentrations had similar day to day changes.

Regression analysis by site of SED weight against SED weight and FC,EC and flow rate are in Table 10. The in-stream S.SED correlated strongly (> 0.9) between all sites. The correlations between SED and FC were not as good as SED vs. SED and were below 0.5 in four comparisons and just above 0.5 in six others. The strongest correlation was a negative one obtained between the FC level at DNI and SED at all sites. EC to SED regression analysis produced correlation coefficients little changed from those between FC and SED. The EC levels at UP were slightly less correlated with SED at all sites, while EC at source and DNI showed similar degrees of correlation and EC at DN2 was somewhat more strongly correlated to SED levels. The strength of correlation of the bacterial parameters with SED weight appeared to be more dependent on the site of the bacterial parameter rather than to the proximity of the FIB and SED sites being

compared, e.g. in only one case (FC vs. SED at DNI) was the strongest correlation obtained when the EC or FC were at the same site as SED. No relationships were apparent between flow and SED.

The regression analysis between bacterial parameters and flow rate (Table 11) showed a good level of correlation between FC and EC at the same site and except at DN1 between different sites. The same lack of correlation between bacterial levels at DN1 and other sites was repeated in the FC to FC and EC to EC comparison.

Flow did not correlate strongly with the FIB parameters, the highest correlation coefficient being between flow and FC at source (0.56) and EC at DN2 (0.57).

Streptococcus Populations - Dry Weather (Table 12)

There was not a great deal of variability in the streptococcal populations from site to site before MSR. The UP site has a slightly higher proportion of S. faecalis var liquefaciens and S. faecium var faecium and lower S. faecium var casseliflavus and S. durans than source or DNI. MSR at source decreased the percent population of S. faecalis var faecalis and S. durans while increasing S. faecium var casseliflavus. The same changes were noted at source and DNI and in addition S. faecalis var liquefaciens and S. faecium var faecium increased their proportion of the population. S. faecalis var zymogenes was also isolated at source after MSR.

Wet Weather

The effect of wet weather on the in-stream streptococcus population at source was to increase S. faecalis var liquefaciens, S. faecium var casseliflavus and S. durans while decreasing S. faecalis var faecalis and S. faecium var faecium. At source and DNI S. faecalis var liquifaciens and S. faecium var faecium changed in the same direction as at UP while other changes tended to be the reverse of the effects noted at UP.

Bacterial Survival - Summer Conditions (Figures 22 and Table 13)

Survival data was obtained for S. faecalis var faecalis and E. coli. Both decreased approximately one order of magnitude over 3 days. The rate of die-off of E. coli was slightly slower than S. faecalis between day 0 and 1, but then appeared to be somewhat more rapid.

Winter Conditions (Figure 23 and Table 14)

Survival data were obtained for S. faecium var faecium and S. bovis in addition to the two bacteria studied under summer conditions.

E. coli died off at a greater rate under winter conditions while the reverse was true for S. faecalis. S. faecium originally decreased at a rate similar to E. coli but then seemed to increase slightly. S. bovis died off most rapidly, decreasing by 4 orders of magnitude within the first 24 hrs. of exposure.

Emery Creek (Industrial Effluents) - Sediment Resuspension

(Figures 24-30 and Table 15)

Dry weather S.SED levels (Fig. 24) in the water column before MSR decreased between UP and source, did not change by DNI, and then showed an increase by DN2. The effect of MSR was to increase concentrations at all sites, particularly at DN1 and somewhat less at DN2. The SED concentrations during wet weather conditions were very close to those obtained following MSR dry weather except at DN2 where they were higher. Intermediate weather conditions before MSR resulted in SED levels slightly lower than wet and dry (after MSR) at UP but very close to dry after MSR at the other sites. The application of MSR caused a large increase in SED levels at UP but little change at the other sites.

Sediment concentrations in Emery Creek were similar under wet and dry conditions and lower during intermediate conditions.

The use of MSR during dry weather caused an increase in FC and EC concentrations at the first three sites and a slight decrease at DN2 (Figs. 25 and 26). FS and ENT responded similarly but levels after MSR were still slightly higher than before the SED resuspension (Figs. 27 and 28). PSA concentrations (Fig. 29) were lower after MSR at DN1 and 2. There was an increase in the levels of all FIB parameters both before and after MSR at source followed by a decrease. The PSA increase was particularly noticeable.

Wet weather bacterial concentrations were higher than those during dry weather, but an in-stream increase at source was still detected.

Densities of FC, EC, FS and ENT during intermediate conditions before MSR lay between wet and dry results. There was no consistent pattern between sites observed but the source impact was still noticeable in all four cases. PSA levels were between wet and dry at UP and DN2 but lower than dry at SOURCE and DN1.

MSR during intermediate conditions (Table 15) caused an increase in FIB concentrations in most cases but there was no consistency to its effect for each parameter. Decreases were noted as a result of MSR for FC, EC at UP and DN1, for FS at DN1 and 2, for ENT at DN2 and/or PSA at source and DN2.

FIB concentrations in the outflow from Emery Creek was highest during wet weather and lowest during dry weather, except for PSA which was recovered from Emery Creek at similar levels during dry and intermediate conditions.

<u>FC/FS</u>

The FC/FS ratios (Fig. 30) and their change was quite variable, depending upon the sampling conditions. Ratios obtained during dry weather before MSR and wet weather, followed the same pattern, first increasing between UP and source and then decreasing and increasing again. Except for source where the ratio was similar, wet weather produced lower ratios than dry

weather. MSR during dry weather resulted in a decrease of FC/FS except at DN1 and a reversal of the between site changes. This same pattern was observed during intermediate weather conditions although ratios were lower. The effect of MSR during intermediate conditions was to further lower the FC/FS ratio except at DN2 where a small increase was noted.

FC/FS within the flow from Emery Creek were similar to those at the in-stream source site during dry and intermediate conditions (before MSR) but were somewhat lower during wet weather.

Post-Rainfall Bacterial (EC/FC) Quality (Table 16)

The largest decrease in EC/FC concentrations, as noted at the two previous sites, was between the day of the rainfall (day 0) and the following day. After day 1 EC and FC levels either decreased over the next two days and then showed an increase or fluctuated up and down. In two cases (source before MSR on day 1 and DN1 after MSR on day 2) EC and FC changed in different directions at the same site, i.e. the concentration of one increased while the other decreased.

EC/FC ratios below 0.6 were evident on day 0 at all sites. In addition there were six other instances in which EC/FC was below 0.6, one before and three after MSR at source, one at DN1 before MSR and one in Emery Creek outflow. The in-stream EC/FC ratios before MSR do not appear to show any day-to-day or site-to-site trends although the source ratio was always lower than

the one at UP and on day 2 it was also lower than Emery Creek. The EC/FC ratio was particularly low on day 4 following rainfall at source and in Emery Creek.

The effect of MSR on EC/FC is almost evenly split between decreasing, increasing or not changing the ratio before resuspension.

The EC/FC ratio in Emery Creek was quite variable being as low as 0.3 and as high as 1.0.

Natural Environmental Phenomena and Bacterial Concentrations (Figures 31 and 32)

The flow at this site appeared somewhat less changeable during each survey than SED or FC and EC and appeared to be decreasing except during storm events (June 24th and August 15).

There was no survey during which all parameters fluctuated according to the same pattern and in fact during the last two surveys FC and EC exhibited different day-to-day changes. During the second survey (June 24) FC, EC and flow showed decreasing trends and FC and flow showed the same type of trend during the last survey.

Regression analysis of SED weight (Table 17) versus SED weight demonstrated a decreasing correlation with distance but remained at or above 0.6 for all comparisons.

The correlations with FC and EC were much poorer particularly when the regression analysis was made using SED concentrations at UP and source. The correlations between SED

and EC (source DN1 and 2) were somewhat higher than with FC. There was also a tendency for the correlation coefficient between SED from each of the sites, and EC or FC at source to be low. SED did correlate with flow at all sites particularly UP and DN1.

Regression analysis of the bacterial parameters (Table 18) showed positive correlations above 0.5 for all comparisons. Distance between sites did not appear to decrease the relationships rather the reverse appears to be the case.

The effect of source appeared to decrease the correlation coefficients observed except when a source to source comparison was made.

Flow was not as strongly correlated with FC or EC as it had been with SED and was better correlated with EC than FC. Only one regression analysis for FC vs. flow produced a correlation coefficient > 0.5 and that was at UP. EC did not correlate with flow at DN2.

Streptococcus Populations - Dry Weather (Table 19)

At UP before MSR the largest proportion of streptococcal isolates were S. faecalis var liquefaciens followed closely by S. durans. The two S. faecium variants were the next highest in representation.

At source and DN1 the highest percentage population was taken up by S. faecium var casseliflavus followed by S.faecium var faecium/S. durans at source and S. durans/S. faecalis var liquefaciens at DN1.

The effect of MSR at UP was to decrease the population of S. faecium var faecium (not recovered) and var casseliflavus and greatly increase the representation of S. durans. There was a similar effect at source although not as large and S. avium was also isolated. At DN1 the effects were even less dramatic.

The streptococcal population distribution in Emery Creek showed a similar pattern as found at source but S. faecium var faecium was higher and S. faecium var casseliflavus was lower.

Wet Weather

The most dramatic rainfall effect at UP was an increase in S. faecium var casseliflavus while S. faecium var faecium, S. faecalis var liquefaciens and S. durans all had decreased representations. At source the net effect was the opposite of that at UP with quite a large increase in the percent population of S. faecalis var liquefaciens. The changes at DN1 were similar to those at source except that the increase in population of S. faecium var faecium was the largest change noted.

The Emery Creek streptococcal population distribution showed little change from dry to wet weather conditions.

Bacterial Survival - Summer Conditions (Figures 33 - 34, and Table 20)

Survival studies were run in both large (100 ml) and standard size (50 ml) diffusion chambers. E. coli and Klebsiella pneumoniae (KP) run in large chambers (Fig. 34) showed that the

die-off, for the two was very similar and rapid; at 72 hrs. *in situ* neither concentration was above 1 per ml. *S. faecalis* and *S. faecium* were also run at this site in the large chambers (Fig. 34). *S. faecalis* died off more rapidly than EC or KP while *S. faecium* initially died off more slowly but it too could not be recovered after 72 hrs.

When EC and the two streptococci species were incubated *in situ* in the smaller chambers (Fig. 33) the effect varied. EC died off more slowly and in fact appeared to increase in concentration between days 2 and 3. *S. faecalis* decreased more rapidly in density between day 0 and 1 and could not be recovered at 48 hrs. while *S. faecium* followed a very similar decline to that in the larger chambers.

Winter Conditions (Figure 35 and Table 21)

Results are only available for *E. coli* because of contamination of diffusion chambers due to membrane puncture. The survival pattern of EC was different than that obtained during the summer (standard chambers). EC died off between day 0 and 1 and day 2 and 3 while showing little change in concentration between day 1 and 2. The net effect was to have a lower concentration after 72 hrs. of *in situ* incubation than during the summer.

James Gardens (Waterfowl Roosting Area) - Sediment Resuspension (Figures 36 - 42, and Table 22)

Dry weather in-stream levels of S.SED before MSR (Fig. 36) varied noticeably between sites with the highest concentration at source. SED levels increased considerably as a result of MSR with a downstream change that was similar to that determined before MSR although the SED at DN1 did not drop below the level at UP.

At this location the SED levels during wet weather were higher than dry before MSR but lower than dry after MSR. The pattern of change between sites had also changed with DN1 and 2 being higher than UP and source.

Intermediate weather conditions resulted in almost no change in SED between sites (before MSR). Levels were between wet and dry (before MSR). MSR during intermediate conditions (Table 22) increased SED concentrations above those occurring under wet conditions and above dry after MSR at UP. Levels decreased slowly in a downstream direction.

The FIB, particularly FC and EC (Figs. 37 and 38), did not show a great deal of variability under dry conditions before MSR. FS showed a slight drop between UP and source while ENT continued the same decrease to DN1 and then increased. PSA demonstrated a different pattern, increasing from source to DN1 and then decreasing. MRS resulted in some increase in FIB levels with a particularly large increase at source. ENT (Fig. 40) did not

show as dramatic an increase in concentration at source as the other parameters.

Wet weather caused a major increase in FIB resulting in levels that were the highest observed, except during dry after MSR at source for FC and EC. Again there was very little change in FIB levels between sites. FC, EC and FS fluctuated up and down to a slight extent while ENT and PSA appeared to be increasing slowly.

FIB levels during intermediate conditions (before MSR) seemed to parallel dry levels (before MSR) but at higher concentrations ranging between those observed under wet and dry conditions before MSR. The density at source for ENT differed in response in that it was the same as during dry weather. The effect of MSR was to increase all FIB levels at all sites and at all but one point (UP) and the densities observed were above dry after MSR. The levels were not however, above those observed during wet weather.

__FC/FS__

The FC/FS ratio (Fig. 42) increased between UP and source under dry conditions both before and after MSR and then remained relatively stable with a small drop after MSR between DN1 and 2. FC/FS was higher after than before MSR. Conditions during storm events resulted in a reversal of the trend between UP and source followed again by relatively stable levels. The FC/FS ratios were considerably lower than during dry weather at all sites.

Under intermediate weather conditions (before MSR) the FC/FS ratios lay between those observed during wet and dry conditions. The pattern of change between sites was similar to that of dry weather between UP and DN1 but then showed an increase. MSR (Table 22) resulted in an FC/FS increase at UP and DN1 and a small decrease at DN2. The net effect was to produce FC/FS ratios that were similar at UP, source and DN2 with an increase at DN1.

Post-Rainfall Bacterial (EC/FC) Quality (Table 23)

There was a general trend to decreasing EC and FC densities with an increase in the post-rainfall period. The most frequent exception to this trend was FC between the second and third days (day 3, UP, DN1 and DN2 after MSR and source below MSR and DN2 before MSR). EC also increased with FC on day 3 at SOURCE before MSR and both parameters showed a major increase at SOURCE (day 2 after MSR).

There were only two instances, both on day 3 (DN1 after and DN2 before MSR) when the EC/FC ratio was below 0.6. In fact only on the third day following rainfall were ratios obtained that were below 0.7 and in general the EC/FC ratio was higher on day 4 than day 0. The result of MSR was to decrease the ratio in only seven cases, but only three times was the decrease more than 0.1 and twice there was a small increase. The remaining data showed no difference before or after MSR.

<u>Natural Environmental Phenomena and Bacterial Concentrations</u>

(Figures 43 and 44)

Flow appeared to be in a gradual decreasing trend through the survey period with small temporary increases during the second and third surveys and a much larger increase during the fourth (July 15-17). S.SED weight and bacterial concentrations were more variable with a tendency to increase between the first and fourth surveys and then decrease.

The third survey (July 2-4) was the only one during which the four parameters showed similar patterns of change. During the first and fourth surveys flow and sediment weight both decreased and/or increased at the same time while during the second survey FC and EC followed a pattern of change similar to flow.

The regression analysis of SED weight against itself and other bacterial parameters (Table 24) demonstrated a positive correlation between S.SED weight at all sites and a slow decrease with distance.

The correlation between SED, FC and EC was generally poor except between SED at DN2 and FC, EC at all sites.

SED correlated with flow at all sites, the relationship being stronger at source and DN1.

The bacteriological parameters correlated strongly (Table 25) between all locations both within and between parameters. The lowest correlation coefficient obtained was in the FC:FC comparison between source and DN1.

The regression analysis between FC, EC and flow demonstrated no correlation at any site.

Streptococcus Populations - Dry Weather (Table 26)

Half the streptococcal population at UP before MSR was S. durans with S. faecalis var liquefaciens and var faecalis being about 19%. At source S. durans remained in almost the same proportion but there was an increase in the S. faecium varieties particularly var casseliflavus. At DN1 the S. durans population had decreased, S. faecium var casseliflavus was about the same and S. faecium var faecium and S. faecalis var liquefaciens had increased in percent population representation.

The main effect of resuspending SED at UP was to decrease the S. durans population and increase that of S. faecalis liquefaciens, while at source the main effect was to shift the S. faecalis representation from var liquefaciens to var faecalis. At DN1 the percent population of S. faecalis var liquifaciens increased as did S. durans.

Wet Weather

During wet weather at UP there was a shift in the streptococcus population from S. durans to the two S. faecium varieties. Proportional representation of the different species did not change greatly from those observed at UP. One observation of interest was the isolation of S. avium at source and DN1.

<u>Bacterial Survival - Summer Conditions</u> (Figure 45 and Table 27)

<u>E. coli</u> died off quite rapidly between day 0 and 1 decreasing by approximately four orders of magnitude. The rate of decrease was considerably slower over the following 48 hrs. but by the third day of exposure, the bacterium could only be isolated from one chamber (in low numbers).

<u>S. faecalis</u>, which was also run, showed better survival than EC and didn't show any die-off until after day 1. The total decrease was two orders of magnitude.

<u>Winter Conditions</u> (Figure 46 and Table 28)

Data could only be obtained for <u>E. coli</u> under winter conditions. The pattern of decrease was similar to that observed during the summer but the rate was slower resulting in a decrease of about two orders of magnitude.

<u>Teston Road (Cattle Access Area) - Sediment Resuspension</u> (Figures 47 - 53, and Table 29)

Suspended SED (Fig. 47) under dry weather conditions (before MSR) was the same at all sites, except for a decrease at DN1. The effect of MSR was to greatly increase S.SED concentrations, particularly at source.

The site to site change in SED during wet weather was similar to that observed during dry weather, after MSR, with the highest level occurring at source. However, overall SED weights

obtained were lower than during dry weather after MSR and at UP and DN2 they were the same as dry before MSR.

SED concentrations in-stream, during intermediate conditions before MSR, were lower than both wet and dry (before MSR) levels at UP, between wet and dry (before MSR) at source and between wet and dry (after MSR) at DN1 and 2. After MSR, SED was increased at all sites except DN2. The net effect was to show an increase from UP to source followed by a decrease between source and DN2.

The FIB with the exception of PSA showed similar changes in concentration between sites for dry (before and after MSR) and wet conditions. The tendency was for the largest increase to occur between UP and source followed by relatively stable levels downstream. FS and ENT (Figs. 50 and 51) had somewhat lower densities at DN1 than source or DN2. Wet weather levels of FC, EC, FS and ENT were highest during wet and lowest during dry (before MSR) except at UP where no increase in levels was noted when SED was resuspended. During intermediate conditions (before MSR) FS and ENT levels showed similar trends to those noted above while FC and EC (Figs. 48 and 49) had a second increase in concentration between source and DN1. Intermediate levels (before MSR) were above those observed during wet weather conditions except for FC and EC at source where they fell between the two dry weather levels. MSR increased SED concentrations with the following exceptions; FC and EC at UP and DN1 and ENT at

source and DN1. The overall site to site changes were similar to those observed during dry weather.

PSA (Fig. 52) behaved somewhat differently during dry weather (before MSR), decreasing slightly in concentration between UP and source and then slowly increasing downstream. Under dry (after MSR), wet, and intermediate conditions levels changed from site to site in a similar fashion to the other FIB. The application of MSR during intermediate conditions resulted in a further increase in PSA between source and DN1. PSA concentrations tended to be highest during wet weather and second highest during dry (after MSR) except at DN2 where they were reversed. Intermediate levels were lower than dry (before MSR) at source and DN2 but higher or the same at the other two sites.

FC/FS

The FC/FS ratio (Fig. 53) increased from UP to source and then showed little change during dry (before and after MSR) and wet weather conditions. The FC/FS at DN1 was somewhat higher than at source or DN2. MSR during dry weather had little effect on FC/FS resulting in only a small increase at source. Wet weather FC/FS ratios were lower than dry weather at DN1 and 2, the same at UP and between dry before and after MSR at SOURCE.

Intermediate FC/FS ratios (before MSR) were lower than those observed under wet or dry conditions except at UP where they were higher. Under intermediate conditions (before MSR) FC/FS was lowest at source and highest at DN1. MSR increased FC/FS at

source and lowered it at UP and DN1. Thus the FC/FS ratio after MSR first increased and then very slowly decreased.

__Post-Rainfall Bacterial (EC/FC) Quality__ (Table 30)

EC and FC levels decreased between day 0 (rainfall) and day 1. At UP and source (before MSR) levels continued to decrease between days 1, 2 and 3 with an increase on the fourth day following rainfall. All other cases showed a temporary increase at day 2.

Only two EC/FC ratios were below 0.9, these were at UP day 0, before MSR and DN1 day 0, after MSR which were 0.8 and 0.7 respectively.

__Natural Environmental Phenomena and Bacterial Concentrations__ (Figures 54 and 55)

Flow measurements were not obtained during the first survey due to difficulties with the staff gauge. During the remainder of the survey periods flow was relatively consistent except for a high flow on June 24th.

FC, EC and SED showed much more variability than flow, with no apparent trends over the summer.

The bacterial parameters and SED followed the same pattern of change during the first survey. __E. coli__ also followed a pattern of change similar to SED during the July 22-24 survey.

The regression analysis with SED weight (Table 31) demonstrated only six correlations in which the correlation

coefficient was above 0.5 these were; SED at DN2 to SED at DN1, FC, EC at UP to SED at UP and FC, EC at DN1 and 2 to SED at DN2.

The regression analyses within and between FC, EC (Table 32) had a much higher level of correlation with no correlation coefficient being below 0.5. The poorest correlations were between bacterial concentrations at UP and the other three sites. No relationships were present between FC/EC and flow.

Streptococcus Populations - Dry Weather (Table 33)

S. faecalis var liquefaciens had the highest percent representation of the streptococcus population at all sites before MSR. At UP only two other species were recovered, *S. faecium* var casseliflavus and *S. durans*, the later being somewhat higher in relative abundance. At source *S. faecium* var faecium was also isolated but the percent population of all three was lower in the streptococcus population than any of the isolates at UP. The relative proportions of streptococcus at DN1 were similar to source but there had been a shift from *S. faecalis* var liquefaciens to the *S. faecium* varieties *S. durans* and *Aerococcus* sp.

The effect of MSR at UP was to decrease *S. faecalis* var liquefaciens (none were isolated) and *S. faecium* var casseliflavus and increase *S. faecium* var faecium (not isolated before MSR) and *S. durans*. Similar effects on *S. faecalis* var liquefaciens, *S. faecium* var casseliflavus and *S. durans* were

noted at source; however, Aerococcus sp. were isolated after MSR which was not the case at UP.

At DN1 the result of MSR was to reduce the percent population of the streptococcus recovered before MSR except for S. faecium var casseliflavus which increased. Aerococcus sp. was present at the same level.

Wet Weather

The main change occurring at UP between dry and wet weather was a decrease in the S. durans population and the recovery of S. faecalis var zymogenes and S. faecium var faecium.

Bacterial Survival - Summer Conditions (Figure 56, and Table 34)

Data was obtained for E. coli and S. faecalis die-off rates during the summer. The die-off of E. coli was more rapid than that of S. faecalis during the first 24 hrs. but little different over the next 24 hrs. At 72 hrs. S. faecalis was recovered at levels approximately four orders of magnitude lower than on day 0, while E. coli could not be recovered (<1/ml).

Winter Conditions (Figure 57 and Table 35)

Data was obtained for E. coli and S. faecium under winter conditions. Both decreased approximately one order of magnitude over the first 24 hrs. with E. coli exhibiting a slightly more rapid decrease. There was no further decrease in levels. S. faecalis var liquefaciens decreased at source during wet weather

while the _S. faecium_ varieties and _S. durans_ increased. _S. faecalis_ var faecalis and var zymogenes were also recovered.

At DN1 the percent distribution of the streptococcus population fell between UP and source. _Aerococcus_ sp. was again isolated at this site.

Bolton Sewage Treatment Plant Sediment Resuspension

(Figures 58 - 64 and Table 36)

The S.SED levels demonstrated the most variability under dry conditions (before MSR). They increased from UP to source then decreased followed by another increase from DN1 to 2. MSR increased SED at all sites and decreased the site to site fluctuations noted before MSR.

Wet weather SED levels were lower than dry (before MSR) at source and DN2, the same at DN1 and somewhat higher at UP. The net result was a decrease in SED from UP to source and not much further change downstream.

Under intermediate weather conditions before MSR the levels of SED in-stream increased gradually from UP to DN1 and then leveled off. MSR increased SED to a greater degree at UP and source than DN1 and 2. The resulting concentrations were lower than those obtained after MSR during dry weather but fluctuated differently from site to site. UP, source and DN2 were approximately the same in S.SED content while DN1 had approximately one third the level. SED during dry and intermediate conditions in the effluent was the same as at UP during dry weather before MSR

while wet weather resulted in somewhat lower S.SED in the effluent.

The FIB concentrations did not show much site to site fluctuation during dry (both before and after MSR) or wet conditions. FC and EC had slightly higher concentrations during dry weather (before MSR) at DN2 than sites upstream but after MSR, which increased levels, the highest densities were at source. Wet weather resulted in higher levels and small fluctuations with the highest concentration at source. Intermediate conditions (before MSR) resulted in some larger site to site changes in FC and EC levels. There was an increase from densities just below those of dry weather (before MSR) at UP, to levels similar to wet weather at source. Levels further increased between DN1 and DN2. MSR resulted in concentrations that were relatively stable and just above those observed during wet weather between UP and source followed by a further increase at DN2, to a level similar to that observed before MSR. The effluent contained FC and EC at densities lower than those in-stream during dry and wet conditions but at levels similar to dry after MSR during intermediate conditions.

FS and ENT showed patterns of site to site change similar to FC and EC but levels at DN1 tended to be the highest during dry weather (before MSR). There was a drop in ENT at source under these conditions. Concentrations during dry weather were higher after MSR than before, and under wet conditions levels were the highest. During intermediate conditions (before MSR) densities

of FS increased between UP and source and then decreased while ENT increased between source and DN2. Except for FS at DN2 and UP, levels were between those observed during dry (before MSR) and wet weather. The effect of MSR during intermediate conditions was to increase densities at all sites but DN1. The levels decreased very slightly from a level just below wet weather levels at UP to a level almost the same as before MSR at DN1. The concentration at DN2 showed an increase above that observed during wet weather. ENT showed a similar pattern but the increase was not as great at DN2 and the level remained just below that observed before MSR.

Effluent concentrations of FS and ENT were also below in-stream levels during wet and dry conditions. Intermediate conditions produced levels of FS similar to in-stream densities during dry weather (before MSR) while ENT levels were higher than other observed concentrations.

The concentrations of PSA fluctuated from site to site in a manner similar to FS during dry weather conditions, but at much lower levels. Levels after MSR were higher than before. Wet weather produced greater increases in concentrations than with the other FIB and there appeared to be an increasing trend between UP and DN2. Densities during intermediate conditions (before MSR) showed greater fluctuation than under other conditions, showing lowest recoveries at UP and DN1 and densities between those under wet and dry conditions (after MSR) at source and DN2. MSR moderated the magnitude of the change by increasing

levels to those observed during dry weather (before MSR) at UP and DN1 and decreasing levels slightly at source and somewhat more at DN2.

The PSA concentrations in the effluent were lowest during dry weather with levels similar to dry weather in-stream after MSR and approximately double this level during wet weather. Densities during intermediate conditions were just above those observed under the same weather conditions at source.

FC/FS

The FC/FS ratios (Fig. 64) also showed little variability and generally remained at or below the ratio at UP. Dry weather (before MSR) produced a slow decrease in FC/FS to DN1 and then an increase to a ratio just above that at UP. The effect of MSR was to increase the ratio except at DN2 thus showing even less fluctuation site to site. Wet weather FC/FS ratios were very similar to those obtained during dry weather (before MSR) except at DN2 where the ratio did not change from DN1.

Under intermediate conditions (before MSR) the FC/FS ratio was similar to the dry weather (after MSR) at UP, slightly higher at source and DN1 and considerably higher at DN2. MSR produced a small increase in FC/FS at UP, source and DN1 and a decrease at DN2 to levels similar to those at the other sites.

The effluent FC/FS ratio did not change much with weather conditions. Wet FC/FS was slightly higher than intermediate which again was slightly higher than dry. The effluent ratios

were similar to those found in-stream under intermediate conditions.

Post-Rainfall Bacterial (EC/FC) Quality (Table 37)

Concentrations of EC and FC in-stream decreased between day 0 and the first post-rainfall day and increased on the last day. There was some site-to-site variability between day 1 and 4. Source and DN1 (before and after MSR) and UP (after MSR) show increased EC and FC levels on the second day followed by a decrease by the third day. UP and DN1 (before MSR) had decreasing concentrations between day 1 and 4 while DN1 (after MSR showed an increase on day 3.

The EC, FC levels in the STP effluent followed a different pattern decreasing from day 0 to 1 and then increasing on day 2 before continuing to decrease through days 3 and 4.

The in-stream EC/FC ratio on rainfall sampling days (day 0) were below 0.5 except at UP where it was equal to 0.5. The effluent ratio on the same day was 1.0. On the post-rainfall days the EC/FC ratios observed in-stream and in the effluent are above 0.6 except at DN1 day 3 before MSR. These levels were greater than those on day 0 in-stream but slightly lower than day 0 in the effluent.

The effect of resuspending the SED differs depending on day and site. In three-quarters of the cases (12) observed, a change took place and this was evenly split between increases (6) and

decreases (6). The changes were relatively small with the largest being an increase at DN1 on day 3.

Natural Environmental Phenomena and Bacterial Concentrations (Figures 65 and 66 and Tables 38 and 39).

The flow at this location appeared to be generally decreasing over the survey period with sharp storm related increases during the second (June 24-26), fourth (July 22-24), and sixth (August 15-17) surveys. The SED concentration dropped considerably during the first survey and increased during the fourth and fifth surveys. The densities of FC and EC showed little within survey variability during the first three surveys but demonstrate somewhat more variability during the second three.

There was no survey in which all parameters varied in a similar pattern day to day. During the fourth survey EC and FC followed the same patterns of change as SED.

Regression analyses with SED weight (Table 38) showed very little correlation on any of the comparisons made. There were only two comparisons run that had correlation co-efficients above 0.5, aside from SED vs. SED at the same location and SED at UP vs. SED at source.

The regression analyses for FC and EC (Table 39) were quite different showing good correlations between most locations. The only location in which the correlation was below 0.5 was between E. coli at UP and DN2 (0.49). The strength of the correlation

appeared to decrease with distance between sites compared for all analyses. Neither FC nor EC correlated with flow.

Streptococcus Populations - Dry Weather (Table 40)

The percent representation of streptococci was similar at UP and source both before and after MSR. The most frequently isolated streptococcus was S. faecium var faecium followed by S. durans and then S. faecalis var liquefaciens and var faecalis. The main difference at DN1 before MSR was that S. durans was present in relatively lower numbers than the two previous sites and after MSR was not recovered at all.

The effluent also had a high population of S. faecium var faecium with S. faecalis var liquefaciens and S. durans present at approximately one quarter the representation of liquefaciens.

Wet Weather

The effect of wet weather was to decrease the percent population of S. faecium var faecium while increasing S. faecalis var faecalis and var zymogenes (not isolated during dry weather) at UP and source. In addition, at source S. faecium var casseliflavus was not isolated as part of the streptococcus population while S. durans decreased. One isolate was identified as S. avium at both sites and three as S. bovis at UP. The changes at DN1 were similar to those at source except that S. durans increased.

The biggest change in the effluent streptococcus population was a shift from S. durans and S. faecalis var liquefaciens to S. faecalis var faecalis.

Bacterial Survival - Summer Conditions (Figures 67 and 68 and Table 41)

This location was also used to run survival studies in large membrane diffusion chambers as well as the standard size during the summer. E. coli and S. faecalis were run in both.

In the standard chambers (Fig. 67) E. coli initially decreased somewhat more rapidly than S. faecalis and it could not be recovered after 72 hrs. in situ. Low numbers of S. faecalis were still present.

In the large chambers (Fig. 68) the reverse trends were observed and in fact there was only a slow E. coli die-off during the last 48 hrs. S. faecalis could not be recovered from the chambers on the third day of exposure.

Winter Conditions (Figure 69 and Table 42)

E. coli decreased somewhat more rapidly over the 72 hr. period of exposure than S. faecalis but die-off rates were considerably slower than during the summer. S. faecium, which was also tested, initially decreased at a rate similar to that of E. coli but concentrations in the chambers after 48 and 72 hrs. were slightly higher than after 24 hrs. of exposure.